Action Research to Improve Students' Problem Solving using Multiple Modes of Representation

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Abstract: Physics students, especially those who are newly introduced to the subject, usually face difficulties in solving real life problems because of most of them are unable to make the accurate mental representation of the problems. This action research aims to improve a teacher's classroom instruction to develop students' problem solving skills by incorporating the use of multiple modes of representation. A class of 30 Form 4 students from a secondary school in Johor, Malaysia involved in the research. A pre-test and a post-test were given to the students to measure their level of achievement in Physics problem solving and the use of representations. Mean scores obtained from the tests were analysed and the result showed that there is a significant increment ($p<.05$) for the achievement in problem solving before and after the instructions. However, a Pearson correlation analysis indicates that there is no significant relation ($p>.10$) between the scores on representation and achievement in problem solving. The implication of this research is that instructors must develop a new plan of action to enable the students to use representations in problem solving. Further research must be carried out to investigate whether a new course of action can improve the result in improving the problem solving skills for Physics students using multiple representations.

Index Terms: Physics Education, Problem Solving

I. INTRODUCTION

Physics is one of the branches of science that many students perceive as very difficult and has a huge amount of workload yet very fascinating [1]. Ornek et al. (2004) had identified factors that made students to believe that physics, in its nature, is a difficult subject. These factors include physics is cumulative or collective, it is very abstract and there are too many things to learn as well as it requires a good mathematical background. Nonetheless, there are various modes of representation available that can be used in physics in order to make it less complicated and easier to understand.

Many researchers and educators have agreed that the use of representations can help students in problem solving as well as understanding the concepts involved in physics. Kohl and Finkelstein (2008) identified that expert problem-solvers are able to use multiple representations with greater flexibility compared to novices. Experts use representations more frequently for the purposes of exploring the problem space, developing a better understanding of the problem situation and assisting them to solve problems [2]. It shows that the use of representations may be the difference between expert and novice problem-solvers.

In Malaysia, the Ministry of Education (MOE) has introduced the 60:40 Science : Arts Stream target at the upper secondary level to ensure that there are enough students opting for the Science stream in order to fulfil the nation's required human capital to make Malaysia a developed country. However, this target was never achieved, instead the percentage of students in the science stream keeps on declining over the years [3]. Based on a survey conducted by the Ministry of Science, Technology and Innovation (MOSTI, 2014), one of the reasons given for the low enrolment in science stream is that people perceived science subjects as difficult (53.1%). It has also been proven in the Trends in Mathematics and Science Study (TIMSS) and Programme for International Student Assessment (PISA) that the students' average score has dropped from being above the international average to below international average from 1999 [4].

Zooming into Physics, an examination into the Report of Commentary on the Quality of Students' Answer on Physics Paper 2 SPM 2013 (LP, 2014), the overall performance of the Form 5 students was average. The students' ability to present physics concepts and to solve quantitative problems that involve applications was mediocre. There are some students who were exceptionally poor in science process skills such as making observation or comparing and contrasting. The students were unable to provide the correct answers because they had trouble understanding the situations given in the problems and sometimes they were unable to identify what the questions required. The answers given by these students were completely off the point and were not related to the questions at all. The students had trouble defining the problems which is the starting point of the problem solving steps. suggested that in defining a problem, students should visualize the events described using a sketch and simplify the problem statement to focus on what need to be solved. This requires the students to represent the problem statement in other forms that are easier to follow and straightforwardly showing the physics concepts that are involved [5].

However, according to Angell et al. (2004), students perceived science (especially physics) as a difficult subject because "it requires pupils to cope with a range of different

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forms of representations simultaneously and to manage the transformation between these different representations".

It is a prominent characteristic that differentiate between an expert problem-solver from a novice: the ability to use multiple representations with greater flexibility (Kohl & Finkelstein, 2008). If the students were able to master the use of representations to define the problem situation, it will help them to solve problems better. Starting 2014, all national examinations in Malaysia will have several items that are constructed to elicit students' higher order thinking skills (HOTS) where the questions are posed into an application type problem statement. For low-achieving students who are already struggling to learn and understand the concepts in Physics will likely have more difficulty in solving the HOTS items.

II. LITERATURE REVIEW

Rosengrant et al. (2007) define representation as "something that symbolizes or stands for objects and or processes". The modes or types of representation used in physics include words, pictures, diagrams, graphs, computer simulations, mathematical equations, etc. Several studies have been carried out to investigate the relation between using representations and the student's performance at solving problems. De Cock (2012), through his research, found that student performance can be influenced by the representational format used in the problem formulation. A similar question was formulated in three different formats: verbal, graphical and pictorial. Students were required to answer a multiple-choice question in one of the formats given and to explain their answers. The findings of the research show that the difference between the fractions of students who chose the correct alternative and the fractions of those who correctly answered with correct explanations is highly significant for the pictorial and graphical format but not for the verbal format. This implicates that more students are able to justify their answers correctly using the verbal format as compared to graphical and pictorial format. This is because there are some specific features in the representations that can influence the students' solution strategy or argument. It is more obvious in the graphical or pictorial format but not in the verbal form. A number of students who answered using the verbal format used additional representations such as equations, a sketch or picture and also a graph. This helps them to relate the physics concepts that can be used in the solution. De Cock (2012) confirmed the results of several other papers where he proved that students' problem solving skill can be affected by the various representational forms given in the problems[8]. Students used different problem solving strategies depending on the representations used to state the problem.

However, Heckler (2010) found that asking students to draw force diagrams in their solutions may resulted in a higher chance for them to obtain wrong answers compared to the students who are not prompted to do so. The reasons for this are that students often use their intuitive reasoning rather than a formal solution method and that prompting them to construct the force diagrams will likely make them represent incorrect forces in their diagrams. Heckler suggested that students may already have their own methods of problem solving. Therefore, when teaching formal problem-solving methods, it is important to recognise what the students already understand about solving a problem from a particular topic and later develop their concept into the formal method.

There are a few other studies that showed the use of multiple representations can greatly influence students' problem solving competencies. However, studies on techniques or strategies to teach students how to apply the use of representations in physics problem solving are limited. Kohl et al. (2007) studied the effects of the students' performance when they were being taught multiple representations use with a strongly or weakly directed approach in the classroom. Both approaches were shown to be successful in promoting multiple representation use with the class that took a strongly directed approach used the representations more effectively than the other class.

There are not many studies done about how the use of representations should be taught to the students to help them becoming an expert problem solvers. In a study conducted by [6], it was found that the level of understanding of Form Four students towards the topic of Forces and Motion was low. The research was conducted using an instrument developed by adapting the questions from Force Concept Inventory (FCI) among 300 students from districts in West Coast Malaysia. The results showed that 68.2% students have low understanding towards the concept and no student was at the high or very high categories. The result of this study showed that the students perceived this topic as difficult and therefore were not able to solve the problems correctly.

[7] explored the activities that can promote students' understanding on representations. Three tasks were given to two classes of introductory modern physics students as assignments to work on. The tasks include: (1) evaluating modal representations in two articles; (2) examining multimodal evaluation rubric; and (3) creating a poster using modal representations. In the first task, the students evaluated the articles by identifying the modes of representation used in the articles, investigating their functions and assessing the roles of the representation towards the general meaning. Yesildag Hasancebi and Gunel found that through this activity, the students were able to appreciate the representations used and it helped the students to create their own writings in the form of a poster which is required in the third task. The three most prominent modes of representation preferred by the students were pictures (68.4%), texts (51.3%) and mathematical formulas (33.3%). Others include graph, table diagram, list and animation. They found that representations can provide scaffolding for students to understand the topics learnt. The function of multiple modes of representation is not only to convey the concepts in science but it can be utilized further as a means "to do and learn science".

Nevertheless, their study was at the university level in a modern physics class. With the restrictions imposed by a traditional classroom in a government school that is a bit lacking in modern facilities, research has yet to be done on the strategies that can be applied to students in order to help them develop some analytical skills with the use of multiple modes of representation. Therefore, this research's general objective is to develop teaching method using representation and improve a teacher's practice in developing students'

problem solving skills by incorporating the use of multiple modes of representation in the lessons.

From this, three specific objectives were formed for this research:

1. To determine the mean score obtained by the students on the Representational Fluency Test on the questions from the topic of Forces and Motion[9].
2. To identify the relationship between the score on the Representational Fluency Test and the level of achievement in Physics problem solving for the topic of Forces and Motion[10].

III. METHODOLOGY/MATERIALS

This research took on an action research design to identify the strategy that is suitable to use representations to solve physics problems at government secondary schools in Malaysia[11][12][13]. According to the Ministry of Education, Malaysia (MOE, 2008), action research has two main elements which are 'action' and 'research' and it is very applicable in the field of education because these two elements are usually done simultaneously where action is done during teaching and learning process while research is done to get empirical evidences that can support the action. It enables the teachers to evaluate and improve their teaching practice by studying the problems scientifically through the process of inquiry-discovery. Teachers use action research to improve their teaching practice by studying and reflecting on the problems they have and implementing changes based on the findings. This form of action research is also called a practical action research where it employs a small-scale research project done by individual teachers within a school with the aim of improving practice by narrowly focusing on a specific issue or problem. An action research focuses on a particular issue and tries to find a solution to the problem.

This research utilised a non-random and purposeful sampling. According to Mohd Najib (2003), a purposeful sampling is an approach where the selection of participants is done for particular people with the reason to facilitate and ease the research procedure. This approach is chosen because it is simpler and the respondents are able to represent a small population. Creswell (2012) stated that the respondents selected for purposeful sampling must be the best people to help us understand the issue. For this research, the chosen respondents are Form Four students from a secondary school in Johor, Malaysia where one of the researchers has been teaching physics for more than five years and is still teaching there. There are 30 Form Four students currently in the school with only one class learning physics subject[14].

To assess students' level of achievement before and after the lesson on using multiple modes of representations, the same set of questions of Forces and Motions was used for pre- and post-tests. The period between the pre-test and the post-test was two weeks across 4 periods of lessons. The lessons were designed to show the students the proper steps in problem solving and how the use of representations may help in obtaining the answers. During the lessons, the teacher focused mainly on problems from the topic of Forces and Motion so they also served as a revision for the students. The instruments were developed using different subtopics from Forces and Motion. They contain the subtopics of Linear Motion, Momentum, Forces in Equilibrium, Conservation of Energy and Work. Each question only covers one subtopic where there are two questions for Linear Motion and the rest of the subtopics have one question each. Each question was marked separately for their problem solving and representations used. Marks for problem solving were given based on the steps and answers written. Marks for representations were based on a rubric adapted from Rosengrant et al. (2009) as shown in Table I.

Table I: Sample rubrics for coding of free-body diagrams

Mark	**0**	**1**	**2**	**3**
Adequacy	No evidence of adequacy	Inadequate	Needs improvement	Adequate
Quality of Representation Constructed	No representation is constructed	FBD is constructed but contains major errors such as missing or extra forces. Forces may be pointed in the wrong direction.	FBD contains no errors such as missing or extra forces but lacks a key feature such as labels or forces are mislabelled or do not contain a labelled axis if appropriate. Lengths of force arrows could be incorrect.	The diagram contains no errors in terms of the number of forces, the direction, length of force vectors, and the direction of axes. Each force is labelled so that it is clear what it represents.

IV. RESULTS AND FINDINGS

Before the lessons, the students were given a pre-test to see how they solve problems with their existing knowledge in Forces and Motion. The mean score for N=30 students is 1.10 out of 22 marks. This puts them in the low level of achievement in problem solving (0 – 6). The highest mark achieved by the students is 3 marks. Some students left a few questions unanswered and some just wrote the information given by questions. There were also answers that were derived by combining the information in a random mathematical operation without any specific formula or equation.

After the lessons on the use of representations in problem solving were conducted in class, a post-test was given to the students. The mean score achieved by N = 30 students is 2.37 which is slightly higher compared to the pre-test. However, there were a couple of students who scored at the moderate level (7 – 15). The highest score achieved was 10 marks out of 22 marks. Although on average most students were still unable to answer all the questions, their solutions had improved. A few students did really well in showing their working and representations used.

To determine whether the lessons on using multiple modes of representation in problem solving are able to increase the students' level of achievement in Physics problem solving, their scores from the pre-test and post-test on the problem solving were compared.

A paired sample t-test shows that there is a significant difference between the mean score where the post-test has a higher mean than the pre-test ($p < .05$) as in Table II. This implies that the lessons on the use of multiple representations gave a positive impact on the students' problem solving achievement in Physics.

Table II: Paired sampled t-test result of before and after the action was taken

Test	N	Mean	Sig.
Pre-test	30	1.10	.004
Post-test	30	2.37	

Before the students were introduced to the use of multiple representations in problem solving, they were not expected to be using any representation except for problems where angles involved. Hence only the scores from the post-test will be considered in determining the level obtained by the students for their representations. The mean score for N = 30 students is 3.43 out of 18 marks. The mean score indicates that their level of ability to produce a representation is very low. The highest score obtained by one of the students is 10. A Pearson Correlation Analysis was employed on the scores from the post-test to determine the relationship between the score on the representation and the level of achievement in Physics problem solving for the topic of Forces and Motion and the result shows that there is no significant relationship between the score on the representation and the level of achievement in problem solving ($R = +.28$, $p > .10$). Hence, there is no significant relation between the score on the representation and the level of achievement in Physics problem solving for the topic of Forces and Motion after the lesson.

V. DISCUSSION

Even though the students have low level of achievement in problem solving before and after the instructions, there is a significant difference between the two. This shows that the increase in the mean score may due to the students being taught the use of multiple representations in problem solving. This finding supports [18][19]where they claimed that the use of representations can assist students to understand the problem statement and help them to solve the problem. According to Leonard et al. (2002), novice problem solvers have insufficient knowledge set and their conceptual knowledge and problem-state knowledge are often disconnected or weakly related. However, the small difference in the mean scores indicates that the students were not able to utterly grasp the whole concept of representation. This is shown by their minimal score for the use of representations in solving the problems[20].

Even though they used some modes of representation, mainly pictorial, the representations were generally incomplete. It only helps them to simplify the problems. They were unable to see the concepts or principles underlying the problem situations. This shows their level as novice problem solvers as identified where novice problem solvers can only construct poorly formed representations and that their problem solving is mostly independent of concepts. Most of the representations formed did not indicate the concepts and principles related to the problems[15][16][17].

According to De Cock (2012), formulation of the problem can affect students' answer where they are more likely to explain correctly and choose the correct answer when the questions are in a verbal form instead of in graphical or pictorial form. It is one of the reasons why the problems given to the students are all in verbal form. However, these students are novices that failed to show much improvement even after the intervention. Therefore, they are unable to produce an effective representation for each of the problem. The suggestion by the teacher to use representations must have been perceived as a command rather than a recommendation. This is in agreement with Heckler's (2010) findings where prompting the students to draw a representation will result in a lower score in problem solving[25]. Even though the teacher only tried to subtly encourage them to use representations, some students were clueless about the course of action that should be taken to solve the problem. These students may have tried to develop their representation while not understanding the problem statement at all and this could lead them into constructing a wrong and misguided representation[21][22][23][24].

VI. TEACHER'S REFLECTION

Action research requires teachers to be reflective. This section shares the teacher's reflection after the action taken. In the lessons, the main forms of representation taught to the students were pictorial forms and graphical forms. This was to help the students answering questions that are complex and not straight-forward especially those that involve real life applications. The graphical form was usually used in linear motion to show the relationships between physical quantities. By focusing on only a few representations to teach, the teacher was able to complete the lessons even though the time given was very limited[26].

There were also a few weaknesses arose during the lessons. While working in a group of five during the first lesson, some students were observed to be inactively participating during group discussion. They seem rather clueless and could not provide any answer when being directly questioned by the teacher. Their passive attitude may have been caused by their lack of understanding about the topic. This is the reason why for the second lesson, the teacher decided to group the students in a smaller group, in pairs. Nonetheless, these students required a few more lessons until they are able to achieve the objective which is to develop a better problem solving skill through the use of multiple representations.

The biggest factor that contributes to the weakness of the lesson is certainly the time constraint assigned to the lesson. The intervention could not be introduced earlier because of the requirement to finish the whole syllabus first before any revision can be done. Additionally, at the end of the year the teacher was engrossed with prepping the Form Five students for the national examinations, SPM[27]. Because the school only has one Physics teacher, there is no one else to take over them. The time allocated for Physics class is also limited to only two times a week, two-periods each.

Therefore, it is recommended for teachers who wish to introduce multiple representations to their students in solving Physics problems, special lessons to learn and practice the method must be allocated. It is better to conduct the lesson in pairs so that the students can support each other.

And finally, multiple representation can also be used to learn the Physics concepts through application to strengthen their understanding of the concepts.

VII. CONCLUSION

Through this action research, the teacher has been able to reflect upon teaching methods in order to improve students' problem solving ability. The method of using multiple modes of representation is applicable but it needs to be presented in

another approach so that students are able to build their own representations relevant to the problem statement and their representations should help them to solve the problem correctly. For future research, the students should have been introduced to the use of multiple representations while learning the topic Forces and Motion itself. Rather than using an action research for only one class, the research can be carried out using experimental design with a control group where the students in that group is taught the Physics subject without emphasising on the use of multiple representations in problem solving.

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