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Behaviours of Students When Solving the Assessment of Programme for International Student Assessment (PISA) Mathematical Problems

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Abstract*— Application of mathematical concepts in the real world requires the use of problem solving skill. The skill is also one of the important components in the learning of mathematics at upper secondary schools. In addition, the emphasis on mathematical problem solving skill in Malaysian system of education can result in the improvement in Programme for International Student Assessment (PISA). The success of teaching and learning using problem solving is determined by students' behaviour. Thus, different forms of problem-solving questions allow careful observations to be done on students' behaviour. Consequently, the behaviour of successful and less successful students can be distinguished. Therefore, this study aims to determine how students' behaviour differs when they respond to mathematics questions in PISA. A method of data collection named as thinking aloud was conducted among six Form 2 students. The results of this study showed that successful students emphasised behavioural process of analysing problems and took a lot of time to solve them. Although less successful students behaved quite similar to the successful ones, they did not possess specific domain of knowledge in mathematics. Meanwhile, unsuccessful students showed minor reactions while they were analysing the problems and taking shorter time to answer the questions as compared to the successful ones.

Keywords*— Mathematical problem solving, Programme for International Student Assessment (PISA), students' behaviour, thinking aloud

I. Introduction

The current educational goal focuses on students' abilities to solve problems [1]. Solving mathematical narratives is one of the most important aspects in solving mathematical problems in daily lives. Therefore, the goal of learning mathematics in school is to promote and facilitate students in solving problems [2]. However, students often feel that mathematical problems have only one type of solution, which is by using formulas. The reality is that even teachers are not aware of various methods of problem solving [3]. Consequently, it is hoped that Malaysia's international achievement in PISA can be increased by emphasising the importance of solving mathematical problems. In 2009, Malaysia was positioned at the bottom one-third ranking among the 74 participating countries in PISA's performance. The result is worrying since Malaysia has yet to reach the average standard imposed by Organisation for Economic Co-operation and Development (OECD). In accordance with the objectives of PISA, the questions are focused on application of knowledge and skills in real lives and not solely on mastery of school curriculum by the students [4]. Thus, problem solving assessment is capable of developing students' thinking skills This endeavour is important in order to fulfil one of the objectives in Malaysian Education Blueprint (MEB) 2013–2025, which is to place Malaysia in the top one-third position in PISA within the next fifteen years [5]. Careful observations can be made on the problems which students need to solve. Data on the approaches taken by each student can distinguish between the behaviour of successful and less successful students [6]. Researchers have suggested that educators need to focus on behaviour of successful students because the findings can be used to develop other students' behaviour in solving problems. Reference [7] highlighted that further research is needed to shed light on the importance of problem solving in classrooms to ensure effective teaching and learning. Therefore, this study was conducted to determine the behaviour of students while solving mathematical problems.

II. Research Objectives

The objectives of this research are:

i. To identify patterns of students' behaviour while solving PISA problems.
ii. To identify behavioural differences between successful, less successful and unsuccessful students.

III. Methodology

The design of this study was taken from the problem-solving model by Polya [8], which consists of the process of understanding problem, planning problem-solving methods, and implementing solution and review it to obtain the correct answer. The steps used in Polya's problem-solving

model can influence attitude in problem solving [9] and the ability to solve non-routine mathematical problems. This study used PISA's set of questions because the questions were about problem solving and the researchers would be able to observe the problem-solving process. Subjective questions were selected to give the students the opportunity to propose ideas and appropriate methods [10]. The study population consisted of six Form 2 students with outstanding achievements in mathematics and were selected based on their teacher's recommendations.

Data were collected using the method of verbal expression of thought (thinking aloud) and from interpretation of the students' behaviour while solving a given problem. Video recordings were made during this process to capture the students' thinking process while answering the questions. In addition, the findings were also supported by the students' written work. Anything spoken and gestured besides the students' work were recorded and transcribed. Based on the complete transcript, the researchers were able to explain the research questions addressed in this study. The transcripts of all samples were coded according to the verbal analysis protocols by Foong (1993) in order to determine the differences in the students' behaviours.

Foong's Behavioural Taxonomy (1993)

A study conducted by Foong used taxonomy to identify the process of solving mathematical problems through meaningful behaviour. This taxonomy has become an instrument to identify and code students' behaviour. An authentic and reliable instrument is thus necessary in identifying the actual behaviour during problem-solving process [11]. Foong has identified 28 types of behaviour and coded each with its own unique code.

The technique used in the verbal expression of thought was by producing data from the oral statement of a student. Clear instructions were given before the recording so that each student was able to express all his or her thoughts with minimum disruption. The students were not given any comprehensive training in order to obtain the data for this study. Each student must vocalise his or her thoughts clearly while answering the questions, as if the student was talking to him or herself, regardless of others. Each student must also be consistent and must not only focus on the final answer but throughout the thought process. By reviewing this problem-solving process, Foong has identified five types of behaviour which are most often showcased by students, namely:

i. Heuristically Orienting the Problem
   The strategy used by problem solvers to solve problems and understand the problematic situation.
ii. Heuristically Solving the Problem
   A normal strategy used to determine solutions.
iii. Knowledge of A Specific Domain
   Listing the mathematical facts, procedures, and skills used by the problem solver during the process of solving the problem.
iv. Metacognitive
   Awareness and monitoring by the problem solvers towards their thoughts while solving problems.
v. Affective behaviour
   Expression and emotion shown by the problem solvers.

These five major behavioural classifications have been broken down into 28 specific types of behaviour which have their own codes. Table 1 shows the coding scheme used in this research.

TABLE I. CODING SCHEME [11]

P-CATEGORY	Understands the problem: P1 – reads the entire question P2 – rereads the question or a portion of the question P3 – reconstructs the sentences P4 – examines the dimension of the question P5 – creates an image
H-CATEGORY	Plans and executes the solution method HI – recalls similar problems H2 – draws a diagram H3 – submits an answer H4 – refers to a specific case H5 – guesses and checks H6 – looks for a pattern H7 – makes generalisation H8 – decides on a logical conclusion H9 – checks calculations and final answer
K-CATEGORY	Knowledge of specific domain K1 – applies algorithm or arithmetic K2 – states the facts, principles or theories K3 – applies the procedure for routine problems K4 – misconception in mathematics
M-CATEGORY	Metacognition M1 – suggests a plan M2 – identifies the level of question (easy or complicated) M3 – reviews progress M4 – identifies mistakes M5 – identifies new knowledge Q1 – asks relevant questions N1 – vocalises difficult questions
A-CATEGORY	Affective behaviour A1 – negatively judges self A2 – gives up A3 – expresses emotion

By using Foong's coding, the researcher was able to differentiate between successful, less successful and unsuccessful students. Each sample in this research was classified according to their scores, which was based on the marking system by Malaysian Examination Board. Table 2 shows the range of scores used in this research to categorise the students as successful, less successful, and unsuccessful.

TABLE II. MARKING RANGE AND GRADE

90–100	A+	Successful
80–89	A	
70–79	A−	
65–69	B+	Less Successful
60–64	B	
55–59	C+	
50–54	C	
45–49	D	Unsuccessful
40–44	E	
01–39	G	

IV. ANALYSIS OF FINDINGS

Table 3 lists the scores and categories of all the students after they answered the PISA's mathematics questions. Based on the total scores, one student was categorised as successful, three students were in the less successful

category, and two students were in the unsuccessful category. The analysis of the scores shows that one student has the highest score, another student got a high score, two students obtained medium scores, and other two students had low scores.

TABLE III. STUDENTS; SCORE AND CATEGORIES

Names of Students	Raw Score (%)	Categories
Shuruthi	73.33	Successful
Syafik	53.33	Less Successful
Syahirah	40.0	Less Successful
Chen	40.0	Less Successful
Hamizah	26.67	Unsuccessful
Hafizudin	26.67	Unsuccessful

As shown in Table 3, Shuruthi obtained the highest score of 73.33%. This score places Shuruthi at the highest level among the students and she was categorised as a successful student. Syafik was the second student and he got the high score of 53.33%, placing him in the category of less successful. Meanwhile, Syahirah and Chen both received a score of 40%, placing them in the less successful category. Hamizah and Hafizudin also obtained the same score of 26.67%. They were at the low level and categorised as unsuccessful students.

Overall, almost all of the types of behaviour in Foong's taxonomy model [11] were found in the analysis of the transcribed verbal protocols. All selected students demonstrated satisfactory behaviour. However, not all of the descriptions in each category were shown or expressed by the students for each question. Table 4 shows the frequencies for the overall questions and students' behaviour while solving PISA's mathematics questions.

TABLE IV. FREQUENCY DISTRIBUTION OF STUDENTS BEHAVIOUR FOR EACH CATEGORY

	Successful Student (SS)	Less Successful Students (LSS)			Unsuccessful Students (US)	
Category /Student	Shuruthi	Syafik	Syahirah	Chen	Hamizah	Hafizudin
P (Understands the problem)	34	22	22	29	28	18
H (Plans and executes the solution method)	23	14	28	18	19	16
K (Knowledge of specific domain)	20	13	22	11	9	7
M (Metacognitive thoughts)	11	2	6	3	8	5
A (Affective behaviour)	7	3	1	1	1	1

The behaviours of successful (SS), less successful (LSS), and unsuccessful (US) students showed that they understood the problem. Nonetheless, the successful student showed the highest frequency. All students demonstrated the behaviour of planning and executing solution methods. However, there were no significant differences between all the three groups. A student from the less successful group showed the behaviour of planning and executing the solution method more frequently due to the difficulty of the question. The unsuccessful students were seen as lacking knowledge of specific domains. The successful student had the most frequent manifestation of metacognitive thinking. One of the less successful students also showed relatively high metacognitive thinking. In the case of affective behaviour, the successful student showed the highest frequency. Meanwhile, the less successful and unsuccessful students seldom demonstrated the affective behaviour.

Based on the analysis of the findings, the successful student demonstrated more behavioural processes compared to the less successful and unsuccessful students. The successful student began the process by analysing the problem, and then did the process of problem solving. This student would repeatedly read the questions, and then used a variety of methods when answering. The successful student was observed as being careful when performing mathematical calculations. In the m-category, which is the metacognitive behaviour, this student easily recognised her mistakes before submitting her final answer.

The less successful students also went through frequent behavioural processes compared to the unsuccessful students. They would frequently review their calculations by trying to understand the question's requirements. This study found that these students frequently involved behavioural processes while solving the problems, such as searching for patterns, reviewing the more specific case, making conclusions, drawing diagrams, and submitting answers. Unsuccessful students were observed as not displaying frequent behavioural processes compared to the other students. They were too complacent with the methods that they used without attempting to use other methods. They were overconfident and chose easy steps without reviewing their solution process. They also took the shortest time to answer the questions.

V. DISCUSSION

A. *Successful Student (SS)*

Based on the findings, the successful student equally showed all the investigated behaviour. However, based on the findings, Shuruthi (the SS), took a lot of time during the process of understanding the problems. The SS repeatedly read the questions to understand their requirements. The researcher identified that Shuruthi used the strategy of reading the questions over and over again, even when she had shown her solution steps. Shuruthi was seen as a student who would not give up and would try to solve the problems until she was satisfied. Shuruthi was the only student who correctly answered question one. Her most frequent behaviour was to read the questions repeatedly. While Shuruthi was trying to draw conclusions based on her understanding, she kept failing to obtain the real meaning of the question. From these measures, Shuruthi showed imprecise solution steps towards the final answer. The researcher found that the SS showed less of the proper behaviour while solving these problems compared to the less successful students (LSS).

1	(Read the question)	P1
2	(Reread the question)	P2
22	Emm..(kept quiet while reading the question and checking solution steps)	P2
23	(Read the question and kept quiet for 4 minutes)	P2

(Shuruthi)

Shuruthi solved 4 questions by looking at the patterns and the requirements of the problems. Shuruthi's solution steps were observed to have better organisation and were easier to understand. Based on the findings, Shuruthi showed the most behavioural process for this question. Shuruthi also took a lot of time to understand the problem, plan, and execute the solution. Shuruthi greatly emphasised the process of understanding the problems since she would allocate a long time to understand them. Successful students will produce a more perfect solution [12]. They know their own strengths and weaknesses, and they will focus on the relationships which exist in a given problem. Smart problem solvers also demonstrate the ability to solve problems with ease.

1	(read the question)	P1
2	225,000 steps.. 9km divided by	P2
3	……(erased writing and read the previous question)	M4
4	So, km to m..m to cm	K2
5	9 km = 9,000 m 9,000 m=900,000 cm	K2
6	So… emmm…	A3
7	900,000 divided by 22,500 steps = 40cm	K3
8	(reread the question's requirement)	P2
9	So, 1 m is equal to (erased writing)	M4
10	1cm equals to 40 steps	M5
11	(reread the question)	P2
12	Step length…step length… (underscored the question)	H6
13	(erase again)	M4
14	So…… 1 step=40 cm	H8
15	(recalculated using the calculator and wrote the final answer)	H9

(Shuruthi)

B. Less Successful Student (LSS)

The less successful students would normally display better problem-solving skills [13]. This observation was proven when Syahirah frequently exhibited behavioural processes even though she was not a successful problem solver. An analysis of students' achievements in mathematics in Germany, Japan, the U.S. and the Netherlands in the PISA programme found that students with high achievements might not necessarily demonstrate their problem solving processes well.

Students who are less successful often do not change the form of the problem into a thinking model [14]. In fact, these students would try to solve the mathematical problems without giving suitable descriptions that can help in the process of answering the questions. This can be seen from Chen's transcript for question one. Chen focused more on the process of analysing the problems. During the problem-solving process, Chen identified the committed errors. Chen only focused on how to accurately perform the calculations without considering the real objective of the question. The same thing happened with Syahirah, who focused too much on the calculations. Mathematics is not only about focusing on numbers and calculations; it should be understood based on the actual context of the questions. A lengthy problem does not necessarily require windy solution steps. Only a few steps are needed to get the right answer.

1	(read the question)	P1
2	(read and repeatedly tried to comprehend the question)	P2
3	Cost = 2,500,000	P2
4	Fuel consumption…20/100 times 2,500,000= 700,000… so, 700,000	K3
8	Fuel consumption of 20%… To reduce…	P2
9	0.42…3,500,000 (calculated with the calculator)	K3
10	(erased the solution step)	M4
11	Increment = 0.42 × 3,500,000 = 1,470,000	P4
12	Decrement = 20/100 × (3,500,000+1,470,000) = 994,000 litre	P4
13	994,000/3,500,000 = (turned quite...)	M4

(Chen)

This was unlike Syafik, who was seen to do minor calculations. Based on the following transcript, Syafik involved frequent metacognitive and affective behaviour. During the problem-solving process, it was observed that Syafik spent more time thinking instead of showing the behavioural processes that could be evaluated by the researcher. This observation is supported by a hypothesis by researchers who state that weak students would use less problem-solving strategies compared to smart students [15]. However, Syafik had the highest score among the other LSS, even though he showed less observational behaviour.

8	Ehmmm… (reread the question)	P2
9	Yatch…oh, my!	A3
10	(Shook his head…)	A1
11	2,500,000 divided by 1,176,000 = 2.1258	K1
12	Uhuk uhuk!	N1
13	13/100 times….365= 47 days	K3
14	Answer: 2 years and 47 days	H3

(Syafik)

Overall, there were no significant differences between the successful and less successful students. The SS was able to carefully analyse the problems, which led to the right answers. On the other hand, students who were less successful also underwent the process of analysing the problems well, but they focused too much on the solution steps and numbers. Among the strategies identified to be frequently performed during the problem-solving process by these categories were predicting and reviewing, drawing pictures, making lists, creating tables, performing backwards solution steps, looking for patterns and using logical reasoning, solving simpler problems first, and writing equations [16, 17]. These observations were evident when Syahirah, Syafik, and Chen skipped question one and proceeded to other questions.

C. Unsuccessful Student (US)

Hafizudin and Hamizah belonged to the category of unsuccessful students. Based on the analysed oral transcript, they did not show a lot of behaviour during the process of solving problems. Hafizudin took a very short time to complete all questions. The researcher found that Hafizudin did not focus on the requirements of the questions, did not think deeply, and did not use other solution strategies. They are less successful problem solvers who will use a variety of operations, search for keywords, read the problems quickly, are not concerned with the context of the problem, do not consider the logicality of the answer, do not show seriousness if they are unable to answer during the first attempt, and will not try other strategies to solve the problems. In contrast to the other samples, Hafizudin involved in almost all of the behavioural processes while answering question one. Hafizudin gave an answer by making a random prediction, without thinking about the logicality of the given answer. This was in contrast with the successful students who would show the best and satisfying work.

8	Fuel consumption of 20%. To reduce…	P2
9	0.42…3,500,000 (used the calculator)	K3
10	(erased the calculation steps)	M4
11	Increment = 0.42 × 3,500,000 = 1,470,000	P4
12	Decrement = 20/100 × (3,500,000 + 1,470,000) = 994,000 litre	P4
13	994,000/3,500,000 = (turned silent...)	M4

(Hafizudin)

On the other hand, Hamizah showed frequent behavioural processes for the category of analysing the

problem for question one. Metacognitive behaviour occurred when she was aware of the mistakes she had made, as shown in the following transcript. Reference [18][19] stated some unsuccessful students would fail to apply the appropriate procedures to specific problems. These students would usually manipulate numbers or operations to produce a solution.

1	(read the question)	P1
2	(reread the question)	P2
3	20/100 × 2,500,000 = 500,000. So, he would have saved…	M1
4	Arghh…ok...(erased the answer)	M4
5	2,500,000 divided by 0.42 …(read the question again)	P2
6	After he used…cost…wait..sailing…the cost we used for the yacht would get…so, the diesel…2 million…so, for 1 litre...	P4
7	2,500,000 × 0.42 = 105,000 (wrong)	K4
8	Huhhh…	A1
9	So, 3,500,000 / 0.42 = 8,333,333. hmmm	H5
10	(used the calculator)... 3 years	K4

(Hamizah)

The research findings indicated that US would display less affective behaviour while solving the given problems. Hafizudin did not display any expression of emotion and feelings, while Hamizah did complain when she answered question one. US were not pressured by the questions. They only felt that their responsibility was to solve a given problem without any negative feelings. This finding was in contrast with the successful students. Although they would almost give up and several complaints were reported, their spirits became stronger with every complaint. Students' unstable emotion may be influenced by the spirit of motivation within them [20]. Therefore emotion also plays an important role in determining the success in solving mathematical problems. Students who feel depressed can become more determined and force them to strive forward. Students, who are unsuccessful, have low motivation towards trying to solve mathematical questions [21][22] because they are not confident with their own capabilities. These students will take the safe route by using inaccurate strategies without thinking hard.

VI. Conclusion

Overall, several differences were observed between the students who were less successful and unsuccessful. Unsuccessful students (US) showed less assertive behaviour compared to the successful and less successful students. The US did not spend a lot of time to analyse the problems. Based on the observations, they also chose the easiest way of using only one problem solving method, without even trying other methods. Their specific domain knowledge must also be improved. This is because, generally, students with low grades do not have in-depth knowledge of content. They do not overtly display metacognitive behaviour. However, this type of behaviour is also considered to be important because during this process, students will re-evaluate and revise their solution steps. Students' behaviour while solving problems are important because it can improve the students' skills in solving problems. The behaviour of successful students can be used as benchmark and are useful for teachers in providing an exposure to the appropriate behaviour when solving a problem. The less successful and the unsuccessful students need to improve their skills by learning new structured approaches, put in more efforts, and have definitive goals in order to be motivated to get the right answers. However, the sample population can be expanded further for future researches in order to obtain students' behavioural patterns on a larger scale.

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