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Teachers' and Students' Preliminary Stages in Physics Problem Solving

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Abstract

This paper describes the preliminary stages in physics problem solving related to the use of external representation. This empirical study was carried out using phenomenographic approach to analize data from individual thinking-aloud and interview 8 senior high school students and 7 physics teachers. The result of this study is a set of outcome space that describes the teachers' and students' preliminary stages in solving a physics problem. The outcome space includes three categories, i.e: the Constructing Diagram: Lead to Successful Solution; Constructing Diagram: Lead to Unsuccessful Solution: and No Diagram: Lead to Unsuccessful Solution. Linkage of student-teacher pairs in the same school is found on the pattern of the preliminary stages of their problem solving.

Keywords: category of descriptions, outcome space, phenomenographic, preliminary stages, problem solving

1. Introduction

Problem solving is a crucial element and is integral in the physics domain or any scientific discipline (Ibrahim & Rebello, 2013). Several studies reported role of cognition during problem solving (Kohl & Finklestein, 2006; Cock, 2012; Ibrahim & Rebello, 2013). Ibrahim and Rebello (2013) explored the categories of mental representations that students work with during problem solving of different representational task formats. Results of the study provide insights into the use of representations in problem solving in order to facilitate students' construction of mental models.

Gaigher et al. (2007) and Solaz-Portolés and Lopez (2007) reviewed some studies on experts and novices that identified qualitative analysis and successive representations as a characteristic of expert problem-solving. Research concerned with representational issues has taken many approaches, in mathematics as well as physics, chemistry, and recently statistics education. In order to benefit from using a representation, students should learn how to interpret the representation, how to connect it to reality, and how it relates to other representations of the same concept (Cock, 2012).

Efforts to understand cognitive processes in problem solving have been carried out for at least 100 years. Many approaches have focused on differences between 'expert' and 'novice' problem solvers (Bodner & Domin, 2000; Malone, 2007; Hu & Rebello, 2014). Although many researches are known about the differences between expert and novice problem solvers, knowledge of those differences typically does not provide enough detail to help instructors understand why some students seem to learn physics while solving problems and others do not. A critical issue is how students access the knowledge they have in the context of solving a particular problem (Tuminaro & Redish, 2007). Bodner and Domin (2000) agreed to Smith (1992) that criticized expert-novice dichotomy as unjustly equating expertise with success. They stated that research on problem solving should focus on the differences between successful and unsuccessful problem solvers. The differences of the success could be further studied by comparing stages in problem solving processes.

In the context of the cognitive process, the research results of Ibrahim and Rebello (2013) indicated that students work primarily at the level of propositional mental representation. Cock (2012) examined student success on three variants of a test item given in different representational formats (verbal, pictorial, and graphical), with an isomorphic problem statement. He confirmed results from recent papers where it is mentioned that physics students' problem-solving competence can vary with representational format and that solutions can be triggered by particular details of the representation. He also found that students use different problem solving strategies, depending on the representational format in which the problem is stated.

Mayer (as cited in Solaz-Portolés & Lopez, 2007) stated that the process of problem solving has two steps, i.e: problem representation and problem solution. In the problem representation, a problem solver should transform the problem description to internal mental representation into two stages: problem translation and problem integration. After the problem description is translated into problem solver's internal mental representation, the problem solver is already to understand the problem. Beside the Mayer's idea, aspects of the four steps by Polya (1957) are also considered to strengthen theoretical framework of this research. From metacognition perspective, aspects the third step (carrying out the plan-*check each step*) and the fourth step (looking back-*check the result*) of Polya could be aspects of Mayer's idea in the preliminary stages. This research has relation with research by In'am (2014) but it is different in focus and context, where he analyzed problem solving process of students for the four of Polya's steps in mathematics.

This research focused on the problem representation, especially related to sequences in problem translation and integration. In here, the investigation focused on teachers' and students'preliminary stages characteristics that lead to successful problem solving. The preliminary stages are also considered by referring to conclusion of Pribul and Bordner (1987) and Solaz-Portolés and Lopez (2007). They concluded that the preliminary stages in the problem solving process involve disembedding relevant information from statement of the problem and structuring or transforming the problem into one the individual understands are particularly important in determining the success or failure of the problem solving process. Therefore, the last stage of the preliminary stages is restricted on the problem representation, especially in constructing external representation (for example: diagram(s) and/or equation(s)). In this research, there is no expert-novices dichotomy as stated by Smith (1992) and Bodner and Domin (2000). This paper especially aimed to answer the research questions: How were the teachers' and students' preliminary stages in physics problem solving? The research question was linked to the role of external representation(s) in facilitating a problem solver to a succes of her/his solution. The involvement of the teachers as subjects of the research was to explore possibility of the influence of the instructor's behaviour to his/her student.

2. Method

2.1 Participants

The participants of the research were 8 Grade XII students and 7 physics teachers who have taught the students in the prior learning. The respondents were from 3 school clusters in Palu City, i.e: higher, moderate, and lower cluster. Each cluster was represented by one school. Every school was represented 2 or 3 students and 2 or 3 physics teachers. The students were chosen by using Respondent Selection Test (RST). The RST results were classified as high, medium, and low group. Students who attain the same RST results in each group were randomly chosen to represent the group. The RST covered motion, force and work-energy concept in order to obtain a cohort of cross-section abilities.

2.2 Research Design and Data Analysis

Data collection was carried out by thinking-aloud and semi-structured interviews, where some specific questions were prepared. A serial of unexpected ways of thinking or reasoning was also followed. The interviews were conducted immediately after the thinking-aloud problem solving to ensure that participants still remember the purposes of their procedure. In the activity, the participants were given a physics problem and during thinking-aloud, they explained literally and verbally what they have in their mind. The problem was included in the constant velocity linear motion concept (part *a*) and included the third Newton's Law (part *b*) (Appendix). Even though it appeared in the transcript, part *b* was not included in the analysis). Part *a* was the focus of this paper. The problem solving activities and interviews were recorded using a video camera. The thinking-aloud has no time limit, and it ended when the respondents could not continue anymore.

The research applied qualitative research paradigm by using phenomenography approach. Phenomenography was chosen as the approach of inquiry or methodology with which to answer the research problem stated above. It has become an established methodology in education research as it aims to understand the various ways in which different people experience, perceive or understand the same phenomena (Walsh et al., 2007a, 2007b; Stamouli & Huggard, 2007).

General goal of the phenomenography study is to develop qualitatively an understanding of the different ways of thinking and conceptualizations about a phenomenon (Marton, 1986; Uljens, 1996). These different ways often refer to as "categories of description". A category of description is the researcher's interpretation of the personal conceptions. The outcome of the approach is a set of categories that describe qualitative variation of respondents' ways in experiencing, interpreting, understanding, perceiving or conceptualizing the object of study, phenomena, concepts or activities through the problem solving (Marton, 1986).

Data analysis was initiated from transcribing of thinking-aloud and interview recordings. The researcher reviewed the data and became familiar with them. The researcher returned to the data and extracted significant statements. Each significant statement was taken to formulate a meaning. The meanings from a number of thinking-aloud were grouped or organized in a category of description. This step revealed common patterns or trends in the data. Grouping process of categories of description is the last step of the approach for resulting outcome space.

The interview results were aimed to support the data from the thinking-aloud activity. The recording transcripts were used to re-check the respondents' written answers. The interview results could be a part of a method for looking a credibilty of the research. The method has been carried out by repeatedly checking the recording and transcript of thinking-aloud, cross-check them with written answer and recording and transcript of the interview. Repetition of the process showed that there is a consistency of the research data and interpretation of the data.

3. Results and Discussion

The analysis on the thinking-aloud transcripts resulted in category of descriptions of respondents' early stages in problem solving. The category of descriptions focused on the preliminary stages in the problem representation. The category of descriptions and their key characteristics are presented in Table 1. Each category is explained in detail by providing an example of the students' or teachers' preliminary stages in solving the problem. The problem needs only a little ability of problem solving, and may be approached by several ways. However, it should be noted that all categories were constructed from all collected data and extracted from the transcripts of thinking-aloud and interview through the reduction processes and classifications based on the important themes. Therefore, the individual examples given below, may not display all the key characteristics. The approach has also been adopted by Walsh et al. (2007b).

Table 1. Outcome space of teachers' and students' preliminary stages in problem solving

Category	Key Characteristics	Respondent	
		Teacher	Student
Constructing diagram: lead to successful solution	Understanding problem followed by diagram construction Conducting identification of given and required variables Simultaneously constructing diagram and identifying given and required variables Referring the diagram as guidance to solution Arranging equation based on the diagram Using verbal representation	PTHa, PTHb, PTMc	SHc
Constructing diagram: lead to unsuccessful solution	Conducting identification of given and required variables Constructing diagram Constructing diagram and identifying given and required variables, not simultaneously Arranging equation is not based on the diagram Using verbal representation Rarely referring diagram as guidance to solution	PTMa, PTMb, PTLa, PTLb	SHa, SHb
No diagram: lead to unsuccessful solution	Conducting identification of given and required variables Arranging equation Almost using verbal representation	-	SMa, SMb, SMc, SLa, SLb

Note.

PT(H, M, or L) = Physics Teacher from (High, Moderate, or Low) school category

S(H, M, or L) = Student from (High, Moderate, or Low) school category

a, b, or c = First, Second, or Third Teacher/Student, sequence of respondent in a school

SMb = Second Student from Moderate school category

3.1 Constructing Diagram: Lead to Successful Solution

The following is a transcript of thinking-aloud as an example for this category (Note: symbol {-} means silent, inaudible, or statements were reduced; {---} means silent in long time (around 2-4 seconds), {...} many of statements were reduced, and [*word/sentence*] shows interpretation or notices that made by researcher based on recording or observation). The transcript is completely presented to show the path of problem solving leading to a solution. It could be additional or comparison data in tracking the process from the preliminary stages to the final result. Therefore, we could understand the role of the preliminary stages for the overall process of the problem solving.

> **PTHb:** {...} [*Reads the problem*]. O o o {-} Mass of car A is 1500 kg [*draws a schema while reads the problem*]. Mass of car B is 2000 kg and its velocity is 15 m/s. If initially, the distance of the cars is 100 meters {-} when the car A across a electric pillar. When? {-} This is a killing problem!. When? Are the cars in the same track? If it is different, they will not crash [*Rereads the problem*]. When and where? If they crash, it means that the cars are in the same track. [*writes the data/value of variables*]. When does the crash take place? {-} it means {-} X_a {-} X_b. When does the car A crash B? The requisite of the

crash {-} distance that reached by the cars is 100 meters. $X_a + X_b = 100$. The requisite of the crash. When and where? [*writes formulae V_a and V_b, checks the formulae*]. Ahhhaaa {-} this is correct. It means $X_a = 100\text{-}X_b$, Ya ya [*completes the schema with data of X_a and X_b*], [Calculates X_a and X_b]. t_a should be equal to t_b [*Finishes the calculation*]. How much 100 divided by 2,4? 40. The cars will crash at X_a = 60 meters and X_b = 40 meters. t_a equals to {-} [*Calculates t_a*]. Because $t_a = t_b$ = 4 seconds. [*Rewrites that stated verbally, result of X_a and X_b*]. {...}

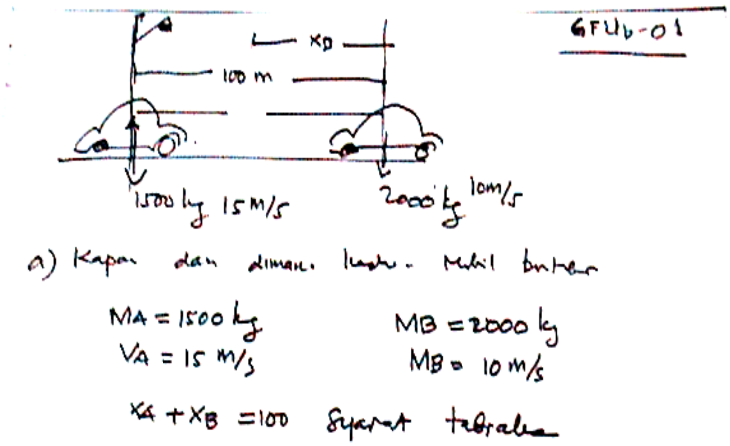

Figure 2. PTHb's written answer at the preliminary stages

In this category, the respondents approached the problem by simultaneously reading or understanding the problem, constructing diagram, and identifying the given and required variables. The process of understanding and analyzing the problem focused on the structural attributes. After the respondents understanding the problem, immediately they constructed diagram and followed by identifying given and required variables. The processes of constructing diagram and identifying variables were conducted with sequences that they could be exchanged and repeated. From the Polya's perspective, the exchange and repetition have relation with the elements of metacognition, implicitly. The given variables were often used to complete the diagram. Analysis of the situation to the structural attributes was supported and eased by the constructed diagram. The variables were written and placed on the diagram or verbally stated during thinking-aloud. Further, the respondents arranged equation(s) to solve the problem based on the diagram. The success key of the problem solving in this category is mainly in the suitability of the constructed diagram. The respondents were always referring the diagram as guidance to a solution during the problem solving process. From the processes, a suitable solution could be obtained. In addition, verbal representations were almost used by the respondents to state the involved concepts and emphasized the solution. This finding confirms the research results by Van Heuvelen (1991), Larkin and Simon (1987), Meltzer (2005), Kohl and Finklestein (2005, 2006) and Gaigher et al. (2007).

In general, the sequences of preliminary stages of problem solving process for this category are presented in the form of schematic in Figure 3.

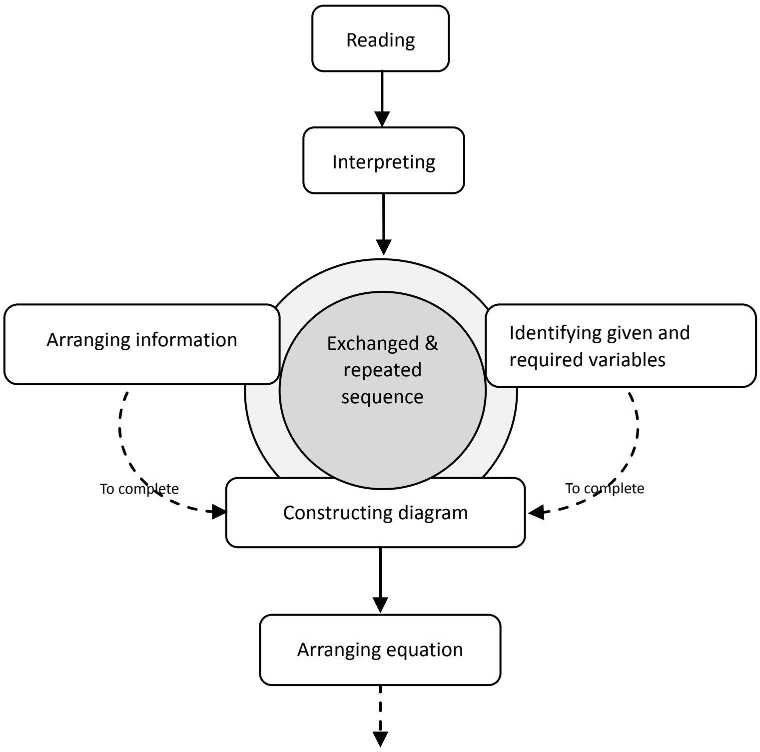

Figure 3. Preliminary stages in problem solving: the first category

3.2 Constructing Diagram: Lead to Unsuccessful Solution

The following is a transcript of thinking-aloud as an example for this category.

> **PTMb:** {...} Car A {-} [*reads overall problem*]. Known: m_a = 1500 kg, m_b = 2000 kg, v_a = 15 m/s, v_b = -10 m/s. $S_b = S_a$ = 100 m. Required: a. t = {-} b. F = {-}. Solution: $m_a v_a + m_b v_b$ = {-}. 1500.15 - 2000.10 = (1500+2000)v'. v' = 0, {-} v' = S/t = 100/ {-}. t = S/v = {...} [*draws diagram*]. Distance of the cars is 100 meters. $S = v_o.t + 1/2\ at^2$. {-} $a = (v_t - v_o)/t$ {-}, $v_t^2 = v_o^2 + 2.a.s.$ {-} a. t and S {-} $S_a = v_a.t_a$, $S_b = v_b.t_b$, $S_a = S_b$, constant velocity linear motion. Is this perfect elastic collision? Is this perfect elastic collision? {-} $(v_b' - v_a)/v_a+v_b) = 1$. In this {-} we don't know magnitude of the velocity after {-} $m_a v_a + m_b v_b$ = {-}.{-} $m_a v_a + m_b v_b = m_a v_a' + m_b v_b'$ {-} 1500.15 - 2000.10 = {...} = 2500 = 1500 v_a' + 2000 v_b' {...} equation 1. Then, I go to restitution formulae. I assume that {-} $1500v_a' + 2500 = 2000\ v_b'$. It means that 3000 {-} oh, no, since there are other factors {-} Auch!!! I get confused in solving this problem {...}

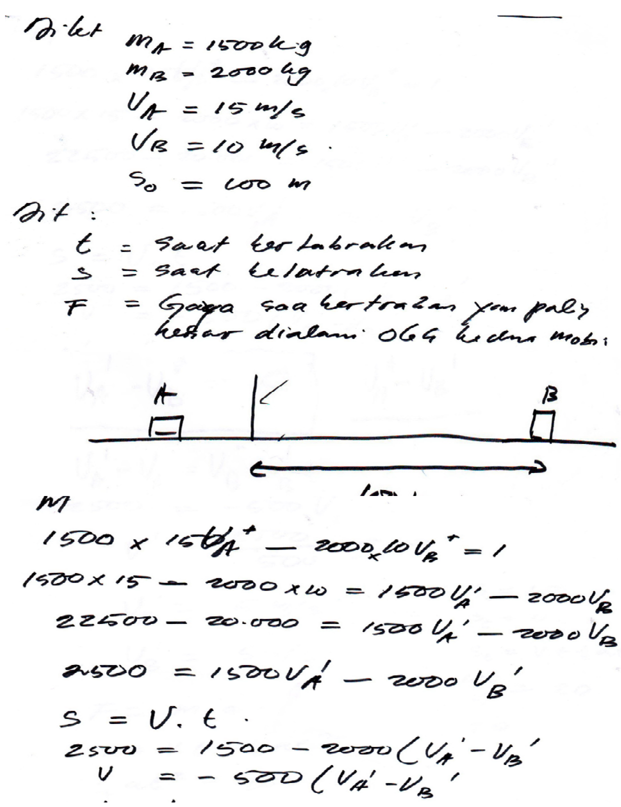

Figure 4. PTMb's written answer at the preliminary stages

The respondents in this category initiated the problem solving by reading the problem followed by identifying the given and required variables, and constructing diagram. The identifying variables and constructing diagram has tendency to be conducted separately. After the process of identifying the given and required variables, they arranged equation based on the relation between given and required variables, not on the constructed diagram. Almost the respondents explained their preliminary stages by using verbal representation. Although they constructed a diagram, the stage was not successful to guide them to a suitable solution. The main factor of the failure to obtain the suitable solution is one stage not supported by the other stages. In other words, each stage seems independent to others. This category of the respondents differs to the first category mainly in the process of arranging equation based on the constructed diagram and identifying the given and required variables.

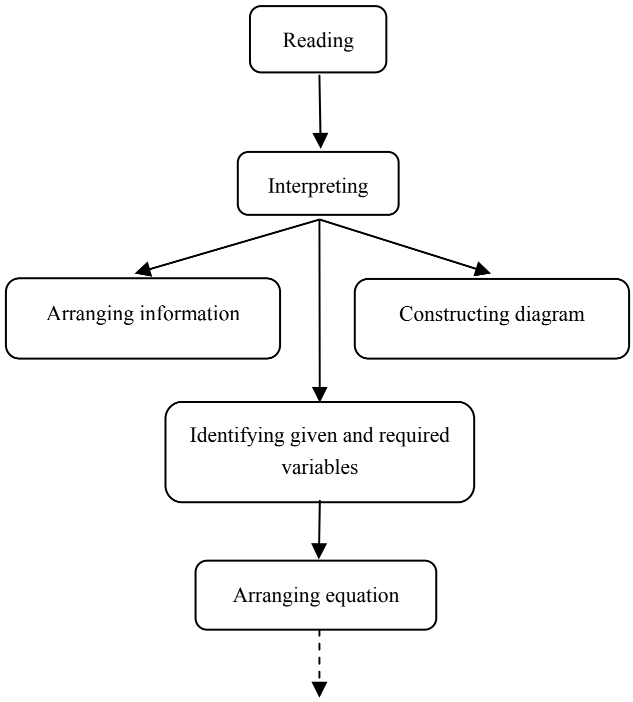

Figure 5. Preliminary stages in problem solving: the second category

3.3 No diagram: Lead to Unsuccessful Solution

The respondents in this category initiated their problem solving stage by reading the problem then followed by identifying the given and required variables. The respondents did not construct diagram during solving the problem. After they identified the given and required diagram, they arranged one or more equations as external representation(s) of situation described in the problem statement. The equations were almost constructed in the form of random and not referred to structural attributes of the problem. The equations were predominant external representation used by the respondents. The preliminary stages of the process outperform the poor of their knowledge about the physical situation included in the problem. The preliminary stages of the respondents did not guide to a successful solution. The respondents in this category seem easy to give up and unconfident to their process. The following is a transcript of thinking-aloud as an example for this category.

> **SMc:** {...} [*reads overall problem; writes the known variables*]. It means to find the magnitude of force. Force is mass times acceleration. Known that velocity {-} known that {-} 15. Gravitation is nine {-}. [*Reads part b*]. 1500 {-} 9,8 [*multiplies 1500 with 9,8*]. Force A = 15000 N, F_b = 20000. Thus, the car feels {-}. When and where? When? It means its time {-} time, v_a = x/t. It means {-} if we want to find its time X/v, it means 100/15 [*calculates*] {-} = 6,6 s. Find the time of b: {-} 100/10 = 0,015. Thus, when do the cars crash?[rereads part *a* of the problem]. {-} 6,6 {-} 0,01. {...}

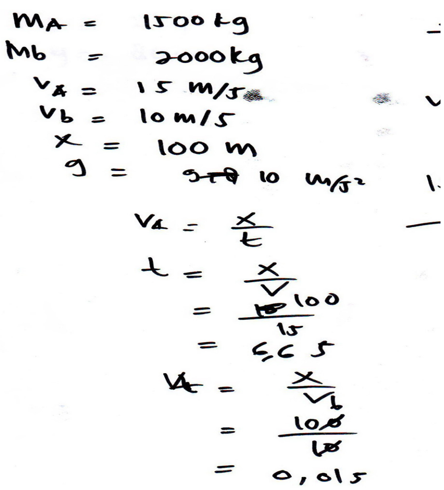

Figure 6. SMc's written answer at the preliminary stages

In general, the preliminary stages of problem solving for the respondents in this category could be schematically described in Figure 7.

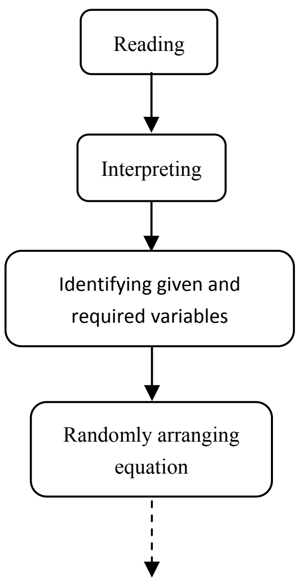

Figure 7. Preliminary stages in problem solving: the third category

Table 2. Formation of teacher-student pairs related to the use of diagram

Aspect	Respondent														
	PTHa	PTHb	SHa	SHb	SHc	PTMa	PTMb	PTMc	SMa	SMb	SMc	PTLa	PTLb	SLa	SLb
Constructing diagram	1	1	1	1	1	1	1	1	0	0	0	1	1	0	0
Referring diagram to arrange equation	1	1	1	1	1	0	0	1	0	0	0	0	0	0	0

Note. 1–Yes, 0–No.

A relation between students and their teachers behavior in the preliminary stages could be presented. In case of the utilization of an external representation such as diagram, the interview results show that a teacher that used a diagram has tendency to emphasize the important of the diagram. The following is the interview transcript related to this statement.

Interview with a teacher respondent (PTHb):

Researcher : In the thinking-aloud session, you directly make a diagram. What does it mean?

PTHb : To see the object position

Researcher : Is it an important stage?

PTHb : Yes, it is. Important, in my teaching, the whiteboard is full with diagrams

Researcher : Do you suggest it for your students?

PTHb : Yes I do. The students are suggested to make a sketch, firstly.

Interview with a student respondent (SHa):

Researcher : Why do you use diagrams?

SHa : By the diagrams, the problem is more real

Researcher : How is your teacher in teaching?

SHa : In here [this school] we are taught <…> when we see a problem, firstly, make a sketch so that it is easier.

Although the data should be tested by field study, however, it could be stated that habits and instructional behaviors of teachers while solving a problem in the classroom (as example of problem solving) have possibility to be factors that influence the problem solving behaviors of their students. Table 2 shows that there are student-teacher pairs based on their schools that relates to the preliminary stages.

In this research, the diagram becomes the focus of attention. While drawing the diagram, the first category of the respondents constructed a two-dimensional model of the concrete situation described in the problem statement. Information and unknown quantities were grouped by placing when these were superimposed on the diagram. Such groupings guide the search for principles of physics applicable to different parts of the concrete situation when analyzing the problem, while links between different parts of the problem become visible as shared features between groupings on the diagram (Gaigher et al., 2007). Ease of recognition may be strongly affected by what information is explicit in a representation, and what is only implicit. In particular, problem solvers in domains like physics and engineering make extensive use of diagrams, a form of pictures, in problem solving, and many distinguished scientists and mathematicians (e.g., Einstein, Hadamard) have denied that they "think in words" (Larkin & Simon, 1987). The research of Rosengrant et al. (2006) showed that problem solvers improve their chance of solving a problem correctly if they include concrete diagrammatic representations as part of solving process. The respondents of the first category performed stages that could help them lead to successful solution. This data also support finding of Bauer and Johnson-Laird (1993) that diagrams helped learners solve a problem more effectively and efficiently.

All teachers in this research conducted construction of diagram. However, many of them, especially in the second category, did not refer it when they arranged equation. They separated the diagram from the arranging of equation and situation. It could distract attention from the effort to learn to relate physics to reality (Larkin & Simon, 1987) so that they faced difficulty in the problem solving process. The second category predominantly referred to the given and required variables as guidance in arranging the equation. The behaviour has similarity with finding of Hu and Rebello (2014) that when solving a conventional physics problem, students tended to frame problem solving in physics as rote equation chasing, i.e., plugging quantities into a memorized physics eqauation. These finding emphasize the hypothesis of Rosengrant et al. (2006) that problem solvers are probably aware intuitively that they do not have mental capacity to remember all the information in the problem statement, and thus they use representation to visualize an abstract problem situation.

Table 1 shows that the construction of diagram is not adequate. It has requisite for resulting effective solution. The requisite is the diagram referred mainly during the preliminary stages as the same as the first category. They seem to construct initial representations that activate an inappropriate schema for the problem. According to Bodner and Domin (2000), this could have three different consequences, each of which leads to an unsuccessful outcome: (1) The initial representation does not possess enough information to generate additional representations that contain algorithms or heuristics that might lead to the solution, and the individual gives up;

(2) The initial representation leads to the construction of additional representations, but these representations activate inappropriate algorithms or heuristics and eventually lead to an incorrect solution to the problem; and (3) The unsuccessful problem solver may never actually achieve an understanding of the problem, in spite of the number of representations constructed in an effort to establish a context for the problem. The third consequence could be a question in which the respondents are teachers.

Table 1 shows that there is a tendency of hierarchical of category of students' preliminary stages related to their school category. The students from the higher school category tend to be in the highest category at the hierarchy compared with the students from the medium and low school category. This emphasizes an appropriate aspect of selection of the respondent based on the RST results.

4. Conclusion and Recommendation

An outcome space has been obtained to describe existence of category of descriptions of the preliminary stages of problem solving and the use of external representation. The outcome space is extracted from the transcript records of the thinking-aloud and semi-structured interview with the teachers and students. Three categories of description of the strategies, i.e.: Constructing Diagram: Lead to Successful Solution, Constructing Diagram: Lead to Unsuccessful Solution, and No Diagram: Lead to Unsuccessful Solution. Each category has key characteristics and there are some characteristic components possessed by two categories. In addition, there are formations of student-teacher pairs based on their schools that related to the preliminary stages. The teachers and students conducted the analysis of situation based on the structural attributes of the given problem. The analysis of structural attributes and utilization of an external representation such as making a suitable diagram, guide them to a productive solution. The analysis was also supported by metacognitive thinking process. Teachers and students in the lower category focus on the analysis of superficial attributes and fail to construct a suitable diagram so that their problem solving processes are not productive to guide them to a successful solution.

The current study has a limitation, i.e., only one problem was studied. This makes it difficult to get general pattern on the teachers and students behaviour.

Recommedations of the results are: (a) Teachers need to habitate themselves to construct an external representation mainly diagram and emphasize their students about the importance of the representation; (b) Further studies are required to investigate the behaviours and habits of teachers in giving examples of problem solving and utilization of an external representations such as constructing diagram and arranging equation; and (c) Further quantitative study could be conducted to compare between a teaching uses problem solving by emphasizing the first category (as experimental group) and conventional teaching (as control group).

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References

Bauer, M. I., & Johnson-Laird, P. N. (1993). How Diagrams can Improve Reasoning. *Psychological Science, 4*, 372-378. http://dx.doi.org/10.1111/j.1467-9280.1993.tb00584.x

Bodner, G. M., & Domin, D. S. (2000). Mental Models: The Role of Representations in Problem Solving in Chemistry. *University Chemistry Education, 4*(1), 24-30.

Cock, M. D. (2012). Representation Use and Strategy Choice in Physics Problem Solving. *Physical Review Special Topics-Physics Education Research, 8*, 020117. http://dx.doi.org/10.1103/PhysRevSTPER.8.020117.

Gaigher, E., Rogan, J. M., & Braun, M. W. H. (2007). *Exploring the Development of Conceptual Understanding through Structured Problem-solving in Physics*. OpenUP.

Hu, D., & Rebello, N. S. (2014). Shifting College Students' Epistemological Framing Using Hypothetical Debate Problems. *Physical Review Special Topics-Physics Education Research, 10*, 010117. http://dx.doi.org/10.1103/PhysRevSTPER.10.010117

Ibrahim, B., & Rebello, N. S. (2013). Role of Mental Representations in Problem Solving: Students' Approaches to Nondirected Tasks. *Physical Review Special Topics-Physics Education Research, 9*, 020106. http://dx.doi.org/10.1103/PhysRevSTPER.9.020106

In'am, A. (2014). The Implementation of the Polya Method in Solving Euclidean Geometry Problems.

International Education Studies, 7(7), 149. http://dx.doi.org/10.5539/ies.v7n7p149

Kohl, P. B., & Finkelstein, N. D. (2005). Student Representational Competence and Self-Assessment when Solving Physics Problems. *Physical Review Special Topics-Physics Education Research, 1*, 010104. http://dx.doi.org/10.1103/PhysRevSTPER.1.010104.

Kohl, P. B., & Finkelstein, N. D. (2006). Effects of Representation on Students Solving Physics Problems: A Fine-Grained Characterization. *Physical Review Special Topics-Physics Education Research, 2*, 010106. http://dx.doi.org/10.1103/PhysRevSTPER.2.010106.

Larkin, J. H., & Simon, H. A. (1987). Why a Diagram is (Sometimes) Worth Ten Thousand Words. *Cognitive Science, 11*, 65-99. http://dx.doi.org/10.1111/j.1551-6708.1987.tb00863.x.

Malone, K. L. (2007). The Convergence of Knowledge Organization, Problem-Solving Behavior, and Metacognition Research with the Modeling Method of Physics Instruction. *J. Phys. Tchr. Educ. Online, 4*(2).

Marton, F. (1996). *Is Phenomenography Phenomenology?* Retrieved from http://www.ualberta.ca/

Meltzer, D. (2005). Relation between Students Problem-Solving Performance and Representational Format. *Am. J. Phys., 73*, 463. http://dx.doi.org/10.1119/1.1862636

Polya, G. (1957). *How to Solve It: A New Aspect of Mathematical Method* (2nd ed.). New Jersey: Princenton University Press. https://notendur.hi.is/

Pribul, J. R., & Bordner, G. M. (1987). Spatial Ability and Its Role in Organic Chemistry: Study of Four Organic Courses. *Journal of Research in Science Teaching, 24*, 229-240. http://dx.doi.org/ 10.1002/tea.3660240304

Rosengrant, D., Van Heuleven, A., & Etkina, E. (2006). Students' Use of Multiple Representations in Problem Solving. In P. Heron, L. McCullough, & J. Marx (Eds.), *Physics Education Research Conference (2005 AIP Conference Proceedings)* (pp. 49-52). Melville, NY: American Institute of Physics.

Smith, M. U. (1992). Expertise and the Organization of Knowledge: Unexpected Differences among Genetic Counselors, Faculty, and Students on Problem Categorization Tasks. *Journal of Research in Science Teaching, 29*(2), 179-205. http://dx.doi.org/10.1002/ tea.3660290207

Solaz-Portolés, J. J., & Lopez, V. S. (2007). Cognitive Variables in Science Problem Solving: A Review of Research. *J. Phys. Tchr. Educ., 4*(2). Retrieved from http://www.phy.ilstu.edu/jpteo

Stamouli, I., & Huggard, M. (2007). *Phenomenography as a Tool for Understanding Our Students*. International Symposium for Engineering Education, 2007, Dublin City University, Ireland. Retrieved from http://www.doras.dcu.ie/

Tuminaro, J., & Redish, E. F. (2007). Elements of a Cognitive Model of Physics Problem Solving: Epistemic Games. *Phy. Rev. Spec. Topic-PER, 3*, 020101. http://dx.doi.org/10.1103/ PhysRevSTPER.3.020101

Uljens, M. (1996). *On The Philosophical Foundation of Phenomenography, In Reflections on Phenomenography–Toward a Methodology?* Retrieved from http:// www.ped.gu.se/

Van Heuvelen, A. (1991). A Learning to think like a Physicist: A Review of Research-Based Instructional Strategies. *Am. J. Phys., 59*, 891. http://dx.doi.org/10.1119/1.16667

Walsh, L. N., Howard, R. G., & Bowe, B. (2007a). Phenomenographic Study of Students' Problem Solving Approaches in Physics. *Phy. Rev. Spec. Topic-PER, 3*, 020108.

Walsh, L. N., Howard, R. G., & Bowe, B. (2007b). An Investigation of Introductory Physics Students' Approaches to Problem Solving. *Level, 3*(5).

Appendix

Problem of constant liniear motion and the third Newton's law

Car A mass of 1500 kg and Car B mass of 2000 kg move in the same track and opposite direction. Their speeds are 15 m/s and 10 m/s, respectively. If in initial condition, their distance is 100 m when Car A passes a point. a. When and where is a crash take place? b. Which does car 'feel' a force greater than other?