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An Easy Way to Solve Problems of Physics by Using Metacognitive Strategies: A Quasy-Experimental Study on Prospective Teachers in Tanjungpura University-Indonesia

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Abstract: Problem solving skill is one of focuses of physics teaching and requirements of the 21st century. This study employed a quasy-experimental method to examine the extent of effectiveness of integrating metacognitive strategies with transfer of learning of mathematics knowledges in solving physics problems of sound wave. The intact group random sampling technique was applied. The subjects (prospective teachers) were 39 students of class IV-A as experimental group, and 48 students of class IV-B as control group at Teacher Training and Education Faculty (FKIP) of Pontianak Tanjungpura University enrolled in the fourth semester academic year 2017/2018. A parallel pretest-posttest of essay test consists of 5 items of sound intensity and Doppler effect were administered. The performance of basic prerequisite mathematics knowledge related to sound wave was measured by using a parallel diagnostic test which consists of 20 items of multiple choices. The results revealed that the model was effective in high category increasing the students' physics problem solving competencies ($t = 2.594$, $p < 0.05$) and arising prerequisite mathematics knowledges ($t = 3.041$, $p < 0.05$). In addition, the ability of transfer of learning in problem solving could be promoted as well. Training and modeling intentionally of any problem-solving model should be conducted by instructors.

Keywords: Physics Problem Solving; Metacognitive Strategies; Transfer of Learning; Practice and Modeling

1. INTRODUCTION

Nowadays education policies in almost the entire globe aim to improve learners' skills to solve problems. Problem solving is considered as one of the 21st century's skills, needs, and universal requirements (Shute et al., 2016). The curriculum 2013 of Indonesia confirmed that problem solving requires metacognitive thinking skills that must be mastered by high school students after having any discipline learning process (Kemendikbud, 2013). The task of educators is to acknowledge, cultivate, exploit, and enhance the metacognitive capabilities of all learners (Abromitis, 2009). Teaching problem solving is one of the most important topics of physics education (Dorgu, 2015; Ince, 2018) and physics is ascertained be a potential tool to develop problem solving skills (Adachi & Willoughby, 2013).

Based on tracing study, it is summarized that some learning interventions to improve the ability of students to solve physics problems had been employed in some previous studies as shown in Table 1.

In addition, a number of previous investigations found that students' problem-solving competencies in physics in many countries are low (Ince, 2018). Lack of mathematical skills, inability to apply the concepts and principles of physics properly, and lack of thinking strategies appropriate to problems are regarded as the major obstacles in solving physics problems (Butler & Coleoni, 2016; Körhasan & Ozcan, 2015; Reddy & Panacharoensawad, 2017). Therefore, a forthcoming physics educational research needs to increase problem solving skills and explore the causes in order to overcome learning difficulties (Kereh et al., 2014; Halim et al., 2016; Hwang et al., 2014). It is declared that students who are unable to solve physics problems they faced, they are very likely not able to transfer what they have learned from mathematics to physics (Hollabaugh, 2017; Obafemi & Ogunkunle. 2013; Robello et al., 2015).

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Table 1. Some learning interventions in solving physics problems

No.	Learning Interventions	Researcher (s)
1	Strategy of Multiple-Representation	Kohl et al. (2006)
2	Polya's Problem Solving Strategy	Selçuk et al. (2008)
3	Model Online Knowledge-Sharing Discussion	Hou et al. (2009)
4	The Competent Problem Solver Method	Taale (2011)
5	Strategic Video Games integrated with Self-Reported Problem-Solving Activities	Adachi et al. (2013)
6	Think Aloud Procedure	Docktor el al. (2015)
7	Target-Task Problem Solving Model	Olaniyan and Omosewo (2015)
8	The Use of Monitoring Skills Model	Alii et al.(2016)
9	Systematic Approach to Problem Solving Assisted PheT Animation	Priadi (2016)
10	Heller's Troubleshooting Strategy	Halim et al. (2016)
11	Virtual Laboratory	Gunawan et al. (2018)

Although it is convinced that mathematics knowledges become a prerequisite for learning physics, however, there are only few studies that investigated the impact of basic mathematics concepts on the ability of physics problem solving. Ellis and Bond (2014) claimed that the use of a specific instructional intervention for improving students' problem solving by using metacognitive strategies in physics is far from investigated.

In this study, I developed the Dirkes model (1985) of metacognitive strategies (Djudin, 2017) by integrating it with the transfer of learning of mathematics knowledge as shown in Figure 1.

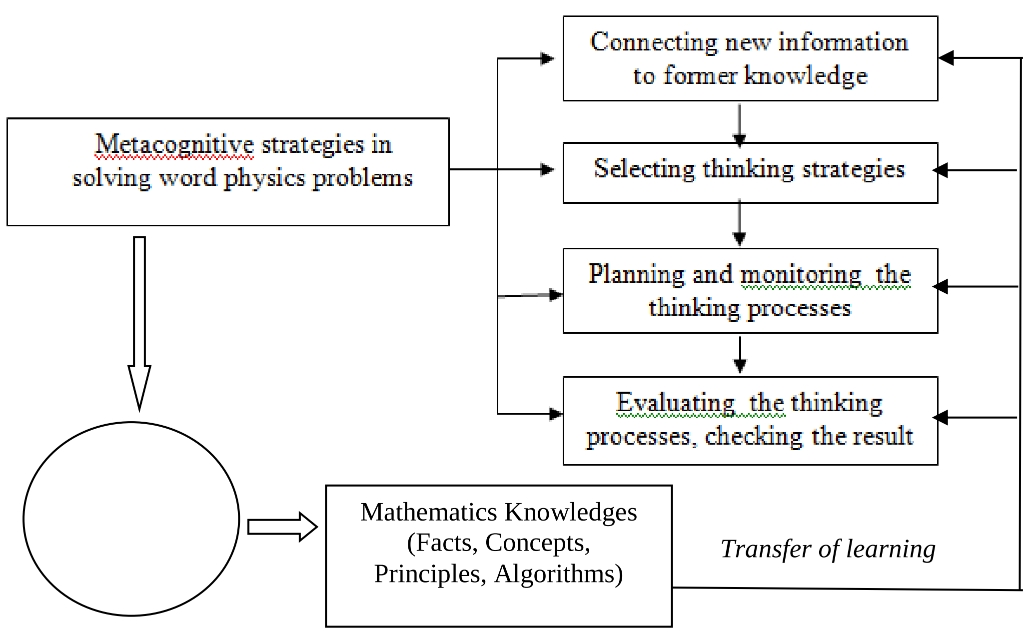

Figure 1. Integration Model of Metacognitive Strategies with Transfer of Learning of Mathematics Knowledges

Redish defined transfer of learning "as the dynamic creation of associations by the learner in a new problem situation" (Robello et al.,2015). According to Robello et al. (2015), transfer of learning of mathematics knowledges is the process of linking and using mathematics knowledges (facts, concepts, principles, and procedures) related to physics problems through the process of horizontal-assimilation and/or vertical-accommodation of the schema (cognitive structure) related to physics concepts or problems.

One of the topics in the physics curriculum that is very essential and often found in everyday life and technology is sound wave (Giancoli, 1990; Walker, 2008).

Unfortunately, the concepts were relatively difficult. In the context of this topic (e.g. intensity of sound, level of sound intensity, and Doppler effect), students in my university physics classes were often unable to use appropriate concepts and principles properly, confused to select the formulas, and showed low acquisition of mathematics knowledges as well. The availability of a gap (incongruence) between physics concepts and mathematics in the school curriculum may be assumed as a source of students' physics learning difficulties. This is one of my empirical problems I endeavor to overcome.

Several previous researchers revealed evidences that the metacognitive strategies are teachable (Koch, 2001; Mitchell, 2015). It is also argued that the instructors need to provide explicit instruction and model intentionally the use of study strategies in the teaching-learning processes (Fadel et al.,2016; Mahdavi, 2014). Therefore, the implementation of the metacognitive model developed in this study is assumed quite rational to increase the problem solving competency in physics.

The main objective of this study is to examine the extent of effectiveness of integrating metacognitive strategies with transfer of learning of mathematics knowledges in the physics learning of sound wave. The differences of students' performances in problem solving and acquisition of basic prerequisite mathematics knowledges related to sound wave between experimental and control group before and after the treatments were examined. The statistical effect of basic mathematics concepts on the ability of physics problem solving after the treatment was analyzed as well.

2. RESEARCH METHOD

The pretest-posttest, non-equivalent control group design was used in this quasy-experimental method (Creswell, 2008). The target population of this research was the total number of students of teacher training and education faculty (FKIP) of Pontianak Tanjungpura University-Indonesia (N= 87) enrolled in the fourth semester academic year 2017/2018. The intact group random sampling technique was applied to determine groups of sample volunteered students (39 students of class IV-A as experimental group, and 48 students of class IV-B as control group). Data for experimental and control goups were pooled in the same semester. The students who were absent during training or data collection were excluded from data analysis.

The independent variables were treatments applied to the two groups. The treatments reflected the research questions were as follows: (1) integrating problem solving model of metacognitive strategies with transfer of learning of mathematics knowledges in the learning of wave sound applied to experimental group; and (2) lecturing model in the learning of wave sound applied to control group.

To execute operationally the problem solving model of metacognitive strategies integrated with transfer of learning of mathematics knowledges (as shown in Figure 1) in the learning of wave sound, the lecturer guided and modelled intentionally the four phases of syntaxes, as follows:

1. *Connecting new information to former knowledge*
   - Reminding the students to previous concepts and principles of physics concept they have learned (e.g power, intensity, level intensity, Doppler effect
   - Relating the basic concepts of mathematics knowledges (e.g fraction, logarithm, scientific notations) to the physics concepts and principles
2. *Selecting thinking strategies deliberately*
   - Sensing the physics problem by reading the text slowly to understand, remembering the symbols, identifying the magnitudes (vectors or scalar) and unit, interpreting the (word) problems
   - Selecting the basic concepts of mathematics knowledges (e.g converting the units)
3. *Planning and monitoring thinking strategy*
   - Sketching or drawing two dmensional-diagrams, writing the appropriate physics formulas or equations in the text (problems)
   - Interpreting the physics concepts and principle by using mathematical interpretations
   - Analyzing to make sure that the two dimensional-graphic (post) organizers (e.g. diagrams, graphs, or sketches) which have been constructed are helpful, make sense, intelligible, or must be revised
   - Doing or executing the computations by using the basic concepts of mathematics knowledges (fraction, logarithm, scientific notations) to find a right solution
   - Monitoring and making sure that all the computation, concepts and physic concept, and mathematical computations are correct
4. *Evaluating thinking processes, checking the results*
   - Rechecking the mathematical procedures and computations based on the physics problem they faced
   - Reinterpreting the physics concepts and principle by using mathematical interpretations and vice versa
   - Making sure that the solutions are correct and plausible by checking or looking backwards

There are two dependent variables in this study. The first dependent variable was the total score on parallel pre- and posttest of students' competencies in problem solving of sound wave collected by administering five items of word problems essay test which consists of one item of sound intensity, two items of level of sound intensity, and two items of Doppler Effect. The reliability coefficient of

Alpha Cronbach for the achievement test was 0.65. The second dependent variable was score on parallel diagnostic pre-and posttest of basic prerequite mathematics related to sound wave concepts measured by using 20 items of multiple choice tests (consist of five items of scientific notation, five items of fraction, five items of algorithm, and five mixing items of the concepts) with three options followed by the reason of calculations. By using this diagnostic test, the misinterpretations or misconceptions of mathematics knowledges could be identified and then reduced. The reliability coefficient of Kruder-Richardson (KR-21) of the test was 0.81. No feedback was given to students after administering the tests, but the scores were reserved for use after the posttest. Students were asked not to discuss their responses or solutions after pretest and posttest. They were promised that they would get a chance to discuss their performances when the posttest was administered. A period of three weeks (three times instructions with 3 x 50 minutes each) were used to carry out the treatments to implement the model of problem solving. Students who were administered the pretest and posttest in a 60 minutes period. Only students who were administered the tests completely were analysed in this study.

The significant difference of students' performances in problem solving of physics and acquisition of basic prerequisite mathematics knowledges between experimental and control group before-after the treatments was examined by using the two independent samples *t*-test ($p < 0.05$). In addition, the Cohen's formula of Effect Size was used to assess the extent of effectiveness of the problem-solving model. The statistical effect of basic mathematics concepts (as a covariate factor) on the ability of problem solving after the treatments was analyzed by using one-way ancova.

3. RESULTS

Pretest

Interval data (scores) gathered from the two groups were analysed by using t-test. Pretesting concluded that there was no significant difference scores of physics problem solving competencies between experimental groups and control group ($t = 0.074$, sig = 0.929, $p > 0.05$) as shown in Table 2. The same results, there was no significant difference scores of acquisition of basic mathematics concepts related to wave sound concepts ($t = 0.039$, sig = 0.962, $p > 0.05$) as shown in Table 3

Table 2. Pretest means of phiysics problem solving competencies

Group	N	Mean	SD	df	*t*- value	sig
Experimental	39	32.84	7.86	85	0.074	0.929
Control	48	31.16	8.58			

Table 3. Pretest means of acquisition of basic mathematics concepts

Group	N	Mean	SD	*df*	*t*- value	sig
Experimental	39	49.20	5.92	85	0.039	0.362
Control	48	47.04	6.18			

The result shows that there were no significant differences between students' physics problem solving competencies of wave sound and acquisition of basic mathematics concepts before manipulating of the treatments.

Posttest

Comparisons of means in posttest between experimental group and control group showed significant differences of students' phiysics problem solving competencies of wave sound ($t = 2.594$, sig = 0.001, $p < 0.05$). Due to significant difference between the two groups, Effect Size (ES) was used to examine the extent of effectiveness of the model as shown in Table 4.

Table 4. Posttest means of physics problem solving competencies

Group	N	Mean	SD	df	*t*- value	sig
Experimental	39	62.40	6.86	85	2.594	0.001*
Control	48	40.65	8.05			
Extent of effectiveness of the model, *ES* = 2.70 (in high category)						

** significant at the 0.05 level*

The result showed that integrating problem solving model of metacognitive strategies with transfer of learning of mathematics knowledges brought about the increase of physics problem solving competencies of wave sound and *ES*-value = 2.70 in high category. Comparisons of means in posttest between experimental groups and control group showed significant differences of students' acquisition of basic mathematics concepts (t = 3.041, sig = 0.005, p ‹ 0.05). Due to significant difference between the two groups, Effect Size (*ES*) was used to examine the extent of effectiveness of the model as shown in Table 5.

Table 5. Posttest means of acquisition of basic mathematics concepts

Group	N	Mean	SD	df	*t*- value	sig
Experimental	39	64.80	7.16	85	3.041	0.005*
Control	48	53.16	6.58			
Extent of effectiveness of the model, *ES* = 1.62 (in high category)						

** significant at the 0.05 level*

The result showed that integrating problem solving model of metacognitive strategies with transfer of learning of mathematics knowledges brought about a significant differences on students' acquisition of basic mathematics concepts related to wave sound concepts and *ES*-value = 1.62 in high category.

The result of one-way ancova to examine statistical effect of basic mathematics knowledge (as a covariate variable) on physics problem solving competemcies after manipulating the two treatments is shown in Table 6.

As depicted in Table 6, the research findings showed a significant influence of integrating problem solving model of metacognitive strategies with transfer of learning of mathematics on students' physics problem solving competencies (*F* = 5.171, sig = 0.004, p ‹ 0.05). It is also concluded that the model could increase the students' physics problem solving performances In addition, the statistical impact of basic mathematics knowledge (as a covariate variable) on physics problem solving of sound wave is also significant ((*F* = 8.025, sig = 0.010, p ‹ 0.05). It means that the increase of students' physics problem solving competencies after the treatments is influenced by students' performances in mathematics and their abilities in process of transfer of learning as well.

Table 6. Analysis of result of one-way ancova Dependent Variable: Problem Solving Competency

Source	Type III Sum of Squares	df	Mean Square	*F*	sig
Corrected Model	235.240[a]	3	78.620	5.395	.007
Intercept	87.408	1	87.408	5.998	.024
Basics Mathematics Knowledges	116.960	1	116.960	8.025	.010*
Model of the treatments	7876	2	3.948	5.171	.004*
Error	287.927	83	3.469		
Total	318.000	87			
Corrected Total	298.334	86			

** significant at the 0.05 level*

4. DISCUSSION

This study concluded that integrating problem solving model of metacognitive strategies with transfer of learning of mathematics knowledges brought about the increase of physics problem solving competencies and performances in basic mathematics knowledges are effective in high category. The finding is relevant to a numerous previous studies. Gök (2006), for instance, investigated the effects of cooperative problem-solving strategies teaching method on high school students' physics success, achievement motivation, and problem-solving attitude, strategy use, and gender and achievement levels. In the experimental study, it was reported that teaching cooperative problem-solving strategies had positive effects on students' achievement and attitude of physics.

Hou et al. (2009) concluded that teachers' and senior high school students' competencies in solving mechanics problems increased significantly after having received the intervention model of Online Knowledge-Sharing Discussion. The study's Adachi et al. (2013) employed Strategic Video Games followed Self-Reported Problem-Solving Activities have been successful in making students feel more fun and joy and also affected on the increase of the abilities of dynamic fluids.

Malone (2018) applied semi-experimental study to investigate the effects of cognitive awareness strategies in problem-solving skills of high school students in physics classes. The study concluded that the students in the experimental group could better apply the cognitive awareness skills than the students in the control group that applied traditional teaching method. In addition, the problem-solving abilities of the students of control group were low and these students showed similar characteristics to novice problem solvers (Malone as cited Ince, 2018). The study of Çalışkan et al. (2010) also found that the teaching problem solving strategies could increase the achievement of first year university students in physics course, cultivate good attitude toward physiscs, and promote self-efficacy as well. Simply stated, the problem solving strategies teaching had positive impacts on physics learning oucomes.

Most previous researches' results were presented in relation to determination of students' ability on general problem solving strategies sub-steps such as drawing diagrams, visualising, using mathematical equations, and concept understanding (Kohl et al., 2006; Körhasan & Özcan, 2015). Kohl and Finkelstein (2006) investigated the effects of mathematical, pictorial, graphical and expressive presentations on problem solving skills of students in physics problems. In this work, which was carried out experimental method with homework including these four dimensions which are mathematical, pictorial, graphical and expressive, it was reported that students can more easily solve the problems indicated by pictorial expressions. This sub-steps had been also carried out and modeled explicitly in the four phases of syntaxes of the model.

De Leone and Gire (2005) investigated the influence of non-mathematical presentation on students' problem-solving competencies in physics involving 39 university students. They argued that the students who solved the given physics problems using mathematical expressions showed more appropriate solutions and successful than those who solved them without using mathematical expressions. It was also recommended in the study that the students with lack of mathematical knowledges need be trained explicitly to solve physics problems through using mathematical expressions (De Leone and Gire as cited Ince, 2018).

As seen from the literature review, if problem solving is assumed as a fundamental skill in some cases, it requires the use of a defined strategy and supports especially the development of expert problem solvers. Simply stated, after identifying the type of knowledge and applying problem-solving methods students should have developed a variety of problem-solving methods to ensure the development of their problem-solving skills (Reddy & Panacharoensawad, 2017).

Costa (1985) stated that problem solving any content-subject matters will employ thinking process involving cognition and metacognition (Costa as cutes Djudin & Amir, 2018). Many previous studies confirmed that problem-solving abilities had been affected by metacognition, mathematics achievement, attitudes, motivation, self-efficacy and self-confidence (Byu & Lee, 2014; Gök, 2014; Docktor el al., 2015). According to Mahdavi (2014), metacognitive knowledge refers to one's knowledge or beliefs about person, task, and strategy variables. These metacognitive knowledges can be modified or revised through the use of metacognitive strategies. Glynn and Muth (1994) identified that metacognitive strategies consist of processes of planning, monitoring, and evaluating our thinking to achieve a certain goal.

Most researchers indicated evidences that metacognitive strategies in problem solving are teachable (Koch, 2001; Mitchell, 2015; Redish, 2004; Schraw et al., 2006). For example, Schraw et al. (2006) found that the metacognitive skills of 171 students in third and fifth grades could be improved through directed learning modeling. To deepen students 'reading comprehension of texts and increase the ability to solve word problems in physics, instructors need to model explicitly the use of metacognitive strategies in their instructions (Djudin & Amir, 2018). In the course of learning to read, for instance, the students should be trained to scrutinize messages in isolation from context, and often in searching the possible meanings and implications, not only memorizing the information they learned (Seraphin et al., 2012). According to Mitchell (2015), to improve students' metacognitive skills, teacher should be a "wrapper" by providing a short intervention (give a few tips) that *surrounds* an existing activity and integrates a metacognitive practice. As students become skillful or experienced in using metacognitive strategies, they might be a more confident, more strategic, and more independent learner (Abromitis, 2009; Yakupoglu, 2012; Zohar & Barizilai, 2013). It is declared that metacognitive strategies will be a critical ingredient to successful learning (Halloun,1996; Koch, 2001), and therefore it is regarded as a fundamental goal of (physics) education.

Based on the findings mentioned above, it is summarized that the use of appropriate problem solving strategies to physics subject matter content could; (1) promote students' conceptual change; (2) cultivate students' situational interest, good attitude, and achievement motivation; (3) make the students feel more confidence, joy, and fun; (4) promote students' self-efficacy and self-regulation; (5) prepare students to be a strategic and independent learner; (6) make students to be skillful or experienced thinkers; (7) increase the students' mathematics knowledges; (8) increase the student ability to interpret the problems they faced in daily activities more logically and systematically; and (9) prepare the students be a good citizen in anticipating the requirements of the future life.

It is also reported that during the treatments in this study, the majority of students in experimental group claimed that using problem solving model of metacognitive strategies integrated with transfer of learning of mathematics knowledges in the physics class was useful, meaningful, and more intelligible. During implementing the model, students are trained to use the thinking (cognitive and metacognitive) strategies intentionally by the lecturer. They also had been explicitly trained to apply and interpret the physics concepts by using mathematics concepts, and vice versa. The use of metacognitive strategies in physics problem solving during the treatment in my class, I hope, should be applied and/or modified by my students in compliance with their own occasions in the further learning in order to increase learning outcomes. This research not only enriches the research literature but also has a significant point of view for problem solving in physics education theory and practice; give a clear insights to apply the problem-solving strategies for the preparation of prospective teachers and future researches.

5. CONCLUSION

It is found that the metacognitive model could increase the students' physics problem solving performances and prerequisite basic mathematics knowledges of sound wave higher than the lecture method training could. The increase of the students' learning outcome after the treatments influenced by the prerequisite mathematics knowledges and their abilities in transfering of learning as well. The result concluded that integrating problem solving model of metacognitive strategies with transfer of learning of mathematics knowledges is effective in high category to improve the students' physics problem solving competencies. The result has some limitations due to the effect of avaiability of uncontrolable factors that may threaten internal validity of the treatment regarding the time-schedule of the two classes and few unsuccesful students reenrolled for taking the course.

The factors affecting problem solving performance e.g problem type, characteristics of problem solvers, their knowledge of the field, conceptual knowledges of mathematics, and metacognitive features may be investigated for forthcoming studies. Based on the results, it is possible to offer some recommendation related to the professional training of the model for teachers regarding developing the skills of problem solving in physics.

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