

# The Impact of Problem-Solving Instruction on Middle School Students' Physical Science Learning: Interplays of Knowledge, Reasoning, and Problem Solving

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## ABSTRACT

The purpose of this study is to explore the impact of problem solving instruction on 126 middle school students' learning of physical science in terms of their scientific knowledge, scientific concept dependent reasoning and problem solving ability. This study used a quasi-experiment with one factorial design of instructional approaches (problem solving and traditional hands-on learning). Sixty-one students participated in problem solving while sixty-five students participated in traditional hands-on learning. Results indicate that the problem solving group significantly outperformed the traditional hands-on learning group for both immediate and retaining effect, regardless of scientific knowledge, scientific concept dependent reasoning and scientific problem solving abilities. The regression results also indicated that the scientific concept dependent reasoning test is the best predictor for scientific problem solving ability, followed by scientific knowledge itself. Our study demonstrates that students' scientific knowledge, reasoning and problem solving all are successfully improved after receiving six weeks scientific problem solving.

**Keywords:** physical science, scientific problem solving, scientific reasoning, scientific knowledge, problem solving instruction

## INTRODUCTION

Problem solving involves "actionable knowledge" which embodies the inter-meshing of thought and action (Watts, 1994). Watts further suggested that the practical use of knowledge gives problem solving relevance and also encourages the transfer of knowledge across different subject domains and contexts (Watts, 1994). Studies have indicated that learning to solve problems in scientific domains, such as physics, requires understanding conceptual knowledge (Hambrick & Engle, 2003; Lucangeli, Tressoldi, & Cendron, 1998). Voss, Greene, Post, & Penner (1983) found that domain-specific knowledge was the best predictor of performance in solving ill-structured problems. Other studies have pointed out that reasoning is related to problem solving (Bransford, 1994; English, 1996; Lee & Jeon, 1998), and others have reported that students' reasoning ability can predict their problem solving performance (Cavallo, 1996; Sonnleitner et al., 2013). However, there is a lack of studies exploring whether students' scientific knowledge, scientific concept dependent reasoning and scientific problem solving can be improved by participating in a semester-long problem solving program. Furthermore, there is a shortage of studies that explore the relationship among scientific reasoning, scientific knowledge and problem solving. Thus, our study specifically investigated the effectiveness of problem solving in enhancing students' scientific knowledge, scientific concept dependent reasoning and problem solving ability across time, and the relationships among reasoning, scientific conception and problem solving.

## Literature

Researchers have proposed different models of problem solving. Garrison's (1991) model included the phases of problem identification, problem description, problem exploration, applicability, and integration, and

#### Contribution of this paper to the literature

- This paper demonstrated that the problem solving group significantly outperformed the traditional hands-on learning group, regardless of immediate and retention performance of scientific knowledge, reasoning and problem solving abilities after receiving six weeks scientific problem solving laboratory across a semester.
- The inclusion of problem solving instruction in the normal classroom learning for the middle school students was considered suitable and promising.
- The scientific concept dependent reasoning test is the best predictor for scientific problem solving ability, followed by scientific knowledge itself.

emphasized students' prior knowledge and ability to use their knowledge to develop problem-solving approaches. Other researchers viewed the problem solving process as including representing problems, searching for solutions, and implementing solutions (Bransford, 1994; Jonassen, 1997; Newell & Simon, 1972). Chua et al. (2016) further connected different stages of problem solving learning (meeting the problem, problem analysis and learning issues, discovery and reporting, and solution presentation and evaluation) to different cognitive functions which mainly included looking from different views, generating ideas, making connections, and synthesis. Despite the differences, in general these models share the following attributes for problem solving: extract the given and goal information, search through the mental problem space which accesses prior domain knowledge, connect it to existing knowledge, and implement the solution-finding processes required to act on the problem.

During the construction of a problem representation which is typically the first stage of the problem solving process, certain features of the problem may activate problem-relevant knowledge in memory (Kintsch & Greeno, 1985; Wang & Chiew, 2010). A problem solver's schema containing a solution goal and features matched for that particular type of problem may then be activated. Many studies have shown that problem solving strategies are schema driven. If problem solvers recognize the problem type that they have represented, they can more easily apply the solution that is associated with the problem space (Chen, 2010; Gick, 1986; Hmelo-Silver, 2004; Kirschner et al. 2006). These studies tended to point out that activating prior knowledge and prior experience of solved problems in terms of schema is critical for solving problems successfully. All of these aforementioned studies serve as the basis for developing our problem-solving learning structure. To guide learners in solving complex problems, appropriate instructional support should be provided and integrated into the learning environment (Kirschner et al. 2006; Van Merriënboer, Kirschner, & Kester, 2003). We structured our problem solving scaffolds with five major components: identify known conceptions (search prior domain knowledge from memory) to facilitate solving proposed problem (unknown information), provide more than two possible solutions (provide detailed steps and strategies for each solution), evaluate their own solutions (decide which solution is more plausible and provide explanations), perform the experiment according to the most applicable design, and challenge students' evidence based explanations according to their results.

It has been found that expert problem solvers use strong domain-specific strategies that are also specific to the problem types, an approach which makes them more efficient (Bulu & Pedersen, 2010; Mayer, 1992; Wang et al., 2013; She et al., 2012). In addition, learning to solve problems in scientific domains, such as physics, requires conceptual knowledge (Hambrick & Engle, 2003; Lucangeli et al., 1998). Heller & Hollabaugh (1992) suggested that physics problem solving at the college level can help students learn problem solving strategies. She et al. (2012) reported that college students' chemistry problem solving abilities increased significantly after a semester of online problem solving learning. Voss et al. (1983) found that domain-specific knowledge was the best predictor of performance in solving ill-structured problems. Other studies reported that middle school students' ecology related problem solving ability was correlated with domain-specific knowledge (She et al., 2012). These studies shared similar suggestions of that domain-specific knowledge is critical for problem solving. Interestingly, most of these problem solving studies was conducted in the online learning environment. Hmelo-Silver (2004) conducted a review of problem based researches and reported that the majority of studies focus on higher education as their target but seldom on K-12 education. In short, it is hardly found any studies of problem solving that were implemented in science classrooms or laboratory at the middle school level. To address that research gap, this study specifically designed a semester-long physical science problem solving program for middle school students. The aim of the study was to explore whether problem solving can facilitate better performance among students in terms of both scientific knowledge and problem solving compared to traditional hands-on learning. Moreover, the study sought to determine whether a relationship between students' physical science knowledge and their problem solving performance could be found in a middle school physical science program.

Scientific reasoning has been reported as a core cognitive process in which learners construct scientific conceptions (Lawson & Thompson, 1988; Lawson & Worsnop, 1992; Oliva, 2003). The nature of reasoning pertains to the process of drawing conclusions from principles and evidence (Wason & Johnson-Laird, 1972), moving on

from what is already known to infer new conclusions or to evaluate a proposed conclusion. Schunk (2000, p. 289) suggested that reasoning involves identifying and formulating questions and hypotheses, analyzing elements and defining terms, using information from personal observations and previous inferences, proceeding inductively or deductively, and finally judging the adequacy of a solution. One study suggested that deductive reasoning – the process of reasoning from one or more general statements about what is known in order to reach a logically certain conclusion – is a fundamental part of problem solving (English, 1996; Johnson-Laird, 2000; Rips, 1999). Deduction implies that thinking involves combining existing information by following specific mental operations. Scientists use a general theory or idea to move through a sequence of ideas and arrive at specific conclusions. Gipson, Abraham & Renner (1989) and Lawson & Renner (1975) contended that solving and interpreting genetics problems involves formal-level operations such as combinatorial, proportional, and probabilistic reasoning, which is consistent with Piaget's developmental theory. Cavallo (1996) reported that students' reasoning ability can predict their performance in solving genetics problems. Few studies have either reported that students' earth science problem solving ability is related to their reasoning skills (Chang, 2010) or that problem-based instruction can develop students' scientific reasoning habits in problem solving skills (Becerra-Labra, Gras-Marti & Torregrosa, 2012). Even though some of the studies suggested a relationship between reasoning and problem solving, however, the existence of such a relationship remains debatable, such that more empirical evidence is needed to confirm it. Therefore, this study aims to explore the effectiveness of problem-solving tasks and traditional hands-on learning tasks in terms of students' scientific knowledge, scientific concept dependent reasoning and problem solving performance. This will allow a better understanding of how students' scientific knowledge, scientific concept dependent reasoning and problem solving performance interact with each other.

## PURPOSE

Many studies have demonstrated the relationship between scientific reasoning and problem solving, or that between scientific knowledge and problem solving. However, less research has been conducted investigating the relationship among scientific concept dependent reasoning, scientific knowledge and problem solving performance. Particularly, none of the studies have examined the effectiveness of a semester-long physical scientific problem solving program versus that of a traditional hands-on learning program. In short, our research focuses on three unsolved issues: (1) whether there are any differences between scientific problem solving learning and traditional hands-on learning in terms of students' scientific knowledge, scientific concept dependent reasoning and problem solving performance; (2) whether students' scientific knowledge, scientific concept dependent reasoning and problem solving performance would be improved over time by receiving instruction in scientific problem solving; and (3) what the relationships are among students' scientific knowledge, scientific concept dependent reasoning and scientific problem solving performance.

## METHOD

### Participants

A total of 126 eighth graders recruited from four average-achievement classes in a middle school participated in this study. In the first two classes, consisting of sixty-one participants, received the problem solving tasks (the experimental group), and the other two classes, consisting of sixty five students, received traditional hands-on learning tasks (the control group). Classes were assigned to either the experimental or control groups based upon the students' school science achievement. An ANOVA was performed to test their school science achievement, and it showed that the two groups had an equivalent initial ability ( $F=0.04$ ,  $p=0.884$ ) at the beginning of this study. All of the students received a scientific knowledge test, scientific concept dependent reasoning test and problem solving test before instruction, immediately after instruction, and six weeks after instruction.

### Procedure

Our study took place over two class periods for each problem solving session and one class period for each traditional hands-on session over a total of six weeks. The first week was defined as the practice task. Each class period lasted about 45 minutes. Both groups received the same traditional lecture across the six-week semester, and each received either problem solving or traditional hands-on learning tasks. Two teachers were assigned to teach in each of the two groups. For the experimental group, there were a total of 28 class periods of lecture instruction and 12 class periods of problem solving learning tasks. For the control group, students received 34 class periods of traditional lecture instruction and 6 class periods of step-by-step traditional hands-on learning tasks that covered the same physical science experiment as the experimental group.

The implementation of traditional hands-on learning tasks followed the school's mandatory laboratory textbook. The teacher guided the students to follow the step-by-step procedures in the textbook, including when, where, and how to conduct the experiment. Students followed each step, observed the phenomena, recorded data, and drew conclusions. The students who received traditional hands-on learning worked in groups from beginning to end, including above procedures and discussion. The same experiments for the traditional hands-on group were modified to problem solving tasks. The problem solving group was required to solve the problems according to the structure of problem solving: identify known conceptions (search prior domain knowledge from memory) to facilitate solving proposed problem (unknown information), provide more than two possible solutions (provide detailed steps and strategies for each solution), evaluate their own solutions (decide which solution is more plausible and provide explanations), perform the experiment according to the most applicable design, and challenge peers' evidence based explanations according to their results. When receiving instruction for a problem solving task, students basically work on individually while identifying known concepts, identifying a proposed problem, providing more than two possible solutions, and evaluating their own solutions. Following these steps, the group members will get together to discuss and determine the most applicable experimental designs from a collection of their group members' plans and then perform the experiment. They will then return to working individually on the work sheet to answer application level questions which require them to use the scientific evidence they collected from the experiment. The major difference between problem solving tasks and traditional hands-on tasks is that students need to come up with their own solutions with detailed designs and procedures instead of following the textbook step-by-step procedure. Each of the step-by-step traditional learning tasks only took about one class period to finish. However, the same experiment modified to a problem solving task took about two class periods to finish. Therefore, the traditional hands-on group had more time for lecture instruction than did the problem solving group.

### **Development of Physical Science Problem Solving Tasks**

The problem solving tasks were designed to develop students' problem solving ability. The five problem solving sessions were specifically developed to cover the content of oxidation and reduction, chemical reaction velocity, chemical reaction equilibrium, friction, and water pressure. The design of each problem solving learning task was structured into five steps to scaffold students' ability to solve the problem. The problem solving task was structured to start with identifying known conceptions - students needed to search prior domain knowledge from memory which might help solve the problem. After they identified the known conception, students needed to identify what were the possible factors causing the proposed question in order to help them to solve the problem. Once they finished these two parts, students must then provide more than two possible solutions to solve the problem solving task with proposed steps and strategies. Following that, students must evaluate their own solutions and decide which solution was more applicable, giving explanations and performing the experiment according to the most applicable design. Finally, a set of questions were designed to see whether students were able to interpret the data and results and also give explanations.

For example, one of the problem solving tasks related to oxidation and reduction is to require students to generate two possible solutions in order to identify the rank of chemical activity for three unknown elements. Carbon, three unknown elements (X, Y, Z) powders and their oxides (XO, YO, ZO) powders were given to students. Students followed the problem solving steps to solve the problem ([Appendix I](#)). On the other hand, the traditional hands-on learning tasks also covered the same oxidation and reduction content as the problem solving group and were asked to observe the changes of four elements (magnesium, copper, zinc, carbon) and their oxides after they were heated. The same elements and their oxides powders and their names of elements were given to students ([Appendix I](#)).

## **INSTRUMENTS**

### **Scientific Knowledge Test (SKT)**

The SKT is a multiple choice diagnostic instrument developed for this study to measure students' knowledge of physical science-related concepts before, after, and six weeks after receiving the physical science problem solving learning tasks or traditional hands-on learning tasks. The questions required students to use the knowledge they learned from the physical science. There were six items for topic 3 (chemical reaction velocity) and the other four topics each had seven items, for a total of 34 items. Students received one point for each question they answered correctly, so the highest possible score is 34. The Cronbach  $\alpha$  of the SKT was 0.73 for the pretest, 0.90 for the posttest, and 0.89 for the retention-test.

### Scientific Concept Dependent Reasoning Test (SCDRT)

The SCDRT is a two-tier multiple choice diagnostic instrument that was developed for this study to measure the correctness of students' physical science conception and their reasoning regarding the concepts relevant to the topic of the problem solving teaching before, after, and six weeks after learning. The SCDRT required students to use scientific reasoning to reason and process physical science-related concepts in order to answer both tiers correctly. There were five items for each topic, and each item contained two tiers: the first tier checked whether students had scientific concepts or alternative concepts, and the second tier required students to use scientific reasoning on physical science-related concepts. There were 25 items and each item had two tiers. Students need to answer both tiers correctly in order to receive one point, so the highest possible score was 25. The Cronbach  $\alpha$  of ADRT was 0.71 for the pretest, 0.89 for the posttest, and 0.89 for the retention-test.

### Scientific Problem Solving Test (SPST)

The SPST was developed to measure students' scientific problem solving before, after, and six weeks after problem solving/ traditional hands-on learning. The SPST consisted of five dimensions which require students to 1) identify known conceptions that might help solve the problem, 2) provide possible explanations for the problem, 3) provide two possible solutions to solve the problem, 4) evaluate their solutions and decide which one is the most applicable solution, and 5) interpret data and results. There were six problem solving tasks, and each covered one topic. Each problem solving tasks consisted of five sub-questions specifically designed to measure the five dimensions of problem solving described above. A rubric system was used to code their performance for each dimension. The rubric addressed the correctness of the known conceptions, correctness of explanations, applicability of the solutions, appropriateness of the students' evaluation, and correctness of data and results interpretation. The known conceptions were classified as correct, partially correct, or incorrect, with points awarded of one, half, and zero point. Each solution was classified as applicable, partially applicable, and non-applicable, with points awarded of one, half, and zero. The problem solving performance for each question was achieved by adding the scores of the five dimensions together. The inter-rater reliability was 0.92.

The content validities for all three instruments were established by a panel of six evaluators consisting of five middle school science teachers and a university science education professor, who together ensured that the items were properly constructed and relevant to the physical science learning materials. The expert validities were established by another experienced middle school science teacher and another science education expert.

### Experimental Group Students' Scientific Problem Solving Worksheet Analysis

The experimental group's students' problem-solving performance on the scientific problem solving tasks which they worked individually to answer application level questions in the working sheets was evaluated by a rubric scoring system. The rubric system evaluates their problem-solving performance according to the following five dimensions: identify known conceptions to facilitate solving proposed problem, provide more than two possible solutions, evaluate their own solutions, design and perform the experiment according to the most applicable design, and challenge peers' evidence based explanations according to their results. The rubric combined both quantity and quality measures. For the quality, it addressed the relatedness of the known conceptions, the feasibility of the methods he/she developed, the correctness of the student's evaluation. For instance, the known conceptions were classified as related, partially related, or unrelated, with points awarded of one, half, and zero point. Each solution was classified as workable, partially workable, and non-workable, with points awarded of 1, 0.5, or 0. Each evaluation was classified as correct, partially correct, and incorrect with points awarded of 1, 0.5, or 0. Each design item was classified as workable, partially workable, and non-workable, with points awarded of 1, 0.5, or 0. Each evidence based explanations was classified as correct, partially correct, and incorrect with points awarded of 1, 0.5, or 0. For the quantity, the repeated measure of ANOVA was used to measure any increase in students' problem-solving task performance from task 1 to 5.

## RESULTS

### Scientific Knowledge Test (SKT)

One-factor MANCOVA was conducted to examine the effects of instructional approaches using post- and retention-SKT scores as the dependent measures, and students' pre-SKT scores as the covariate. **Table 1** summarizes the results of the one-factor MANCOVA: specifically, instructional approaches (Wilk's  $\Lambda=0.94$ ,  $p=0.030$ ) had a statistically significant effect on the performance of post- and retention-SKT. Then univariate F (one-factor ANCOVA) was performed to independently examine the effect of the instructional approaches on post- and retention-SKT. This indicated that the effects for instructional approaches on both post-SKT ( $F=4.83$ ,  $p=0.030$ ) and

**Table 1.** Multivariate Analysis of Covariance (MANCOVA) of Post- and Retention- of Scientific Knowledge Test (SKT) Scores, Scientific Concept Dependent Reasoning Test (SCDRT) Scores, and Scientific Problem Solving Test (SPST) Scores

Source of Variance	Wilk's $\Lambda$	Hypothesis df	Error df	Multivariate F
Scientific Knowledge Test (SKT)				
Covariates				
Pre-test scores	0.56	2	122	47.20***
Group memberships				
Instructional approaches	0.93	2	122	4.76*
Scientific Concept Dependent Reasoning Test (SCDRT)				
Covariates				
Pre-test scores	0.73	2	122	23.17***
Group memberships				
Instructional approaches	0.93	2	122	4.68*
Scientific Problem Solving Test (SPST)				
Covariates				
Pre-test scores	0.68	2	122	28.44***
Group memberships				
Instructional approaches	0.70	2	122	25.62***

Note. \*\*\* $p < 0.0001$ , \*\* $p < 0.001$ , \* $p < 0.01$

**Table 2.** MANCOVA and ANCOVA of Instructional Approaches of Post- and Retention- of Scientific Knowledge Test (SKT) Scores, Scientific Concept Dependent Reasoning Test (SCDRT) Scores, and Scientific Problem Solving Test (SPST) Scores

	Univariate F		Post-hoc
	Post-test	Retention-test	
Scientific Knowledge Test (SKT)			
Instructional Approaches	8.37**	5.56*	Post : Problem solving instruction > Conventional instruction (0.005) Retention: Problem solving instruction > Conventional instruction (0.020)
Scientific Concept Dependent Reasoning Test (SCDRT)			
Instructional Approaches	6.85*	8.43**	Post : Problem solving instruction > Conventional instruction (0.010) Retention: Problem solving instruction > Conventional instruction (0.004)
Scientific Problem Solving Test (SPST)			
Instructional Approaches	51.39***	18.78***	Post : Problem solving instruction > Conventional instruction (0.000) Retention: Problem solving instruction > Conventional instruction (0.000)

Note. \*\*\* $p < 0.0001$ , \*\* $p < 0.001$ , \* $p < 0.01$

retention-SKT ( $F=5.67, p=0.019$ ) were significant. Thus, the students' post- and retention-SKT were significantly affected by the instructional approach. The post-hoc analysis for the main effect suggests that the problem solving group performed significantly better than the traditional hands-on learning group ( $p_{(post)}=0.030, p_{(retention)}=0.019$ ) on post-SKT ( $p_{(post)}=0.030$ ) and retention-SKT ( $p_{(retention)}=0.019$ ) (Table 2). In summary, the problem solving group outperformed the traditional hands-on learning group on both post- and retention-performance of scientific knowledge involving physical science.

### Scientific Concept Dependent Reasoning Test (SCDRT)

One-factor MANCOVA was conducted to examine the effects of instructional approaches using post- and retention-SCDRT scores as the dependent measures, and students' pre-SCDRT scores as the covariate. Table 1 summarizes the results of the one-factor MANCOVA: specifically, instructional approaches ( $Wilk's \Lambda=0.91, p=0.006$ ) had statistically significant effect on the performance of post- and retention-SCDRT. Then univariate F (one-factor ANCOVA) was performed to independently examine the effect of the instructional approaches on post- and retention-SCDRT. This indicated that the effects for instructional approaches on both post-SCDRT ( $F=10.43, p=0.000$ ) and retention-SCDRT ( $F=6.33, p=0.002$ ) were significant. Thus, the students' post- and retention-SCDRT were significantly affected by the instructional approach. The post-hoc analysis for the main effect suggests that the problem solving group performed significantly better than the traditional hands-on learning group on post-SCDRT ( $p_{(post)}=0.002$ ) and retention-SCDRT ( $p_{(retention)}=0.013$ ) (Table 2). In summary, the problem solving group

**Table 3.** Stepwise multiple Regression Summary for relationships among Independent and dependent variables for the experimental group

	B	SE B	$\beta$	Sign.	R	R <sup>2</sup>
<b>Post- Scientific Problem Solving Test (SPST)</b>						
Model 1						
(Constant)	0.48	0.90		0.590		
Post-Scientific Concept Dependent Reasoning (SCDR)	1.33	0.11	0.727***	0.000	0.73	0.53
Model 2						
(Constant)	-2.36	1.25		0.061		
Post-Scientific Concept Dependent Reasoning (SCDR)	0.72	0.22	0.390**	0.002		
Post- Scientific Knowledge Test (SKT)	0.48	0.15	0.385**	0.002	0.75	0.56
<b>Retention- Scientific Problem Solving Test (SPST)</b>						
Model 1						
(Constant)	-1.39	0.87		0.110		
Retention -Scientific Concept Dependent Reasoning (SCDR)	1.49	0.12	0.745***	0.000	0.75	0.55
Model 2						
(Constant)	-3.73	1.37		0.007		
Retention -Scientific Concept Dependent Reasoning (SCDR)	1.04	0.24	0.519***	0.000		
Retention - Scientific Knowledge Test (SKT)	0.37	0.17	0.260*	0.031	0.76	0.57

Note. \*\*\* $p < 0.0001$ , \*\* $p < 0.001$ , \* $p < 0.01$

outperformed the traditional hands-on learning group on both post- and retention-performance of scientific concept dependent reasoning involving physical science.

### Scientific Problem Solving Test (SPST)

One-factor MANCOVA was conducted to examine the effects of instructional approaches using post- and retention-SPST scores as the dependent measures, and students' pre- SPST scores as the covariate. **Table 1** summarizes the results of the one-factor MANCOVA: specifically, instructional approaches (Wilk's  $\Lambda = 0.91$ ,  $p = 0.006$ ) had statistically significant effect on the performance of post- and retention-SPST. Then univariate F (one-factor ANCOVA) was performed to independently examine the effect of the instructional approaches on post- and retention- SPST. This indicated that the effects for instructional approaches on both post-SPST ( $F = 10.43$ ,  $p = 0.000$ ) and retention-SPST ( $F = 6.33$ ,  $p = 0.002$ ) were significant. Thus, the students' post- and retention-SPST were significantly affected by the instructional approach. The post-hoc analysis for the main effect suggests that the problem solving group performed significantly better than the traditional hands-on learning group on post-SPST ( $p_{\text{post}} = 0.002$ ) and retention-SPST ( $p_{\text{retention}} = 0.013$ ) (**Table 2**). In summary, the problem solving group outperformed the traditional hands-on learning group on both post- and retention-performance of scientific problem solving involving physical science.

### Stepwise Multiple Regression Analysis among Problem Solving, Scientific Knowledge, and Scientific Concept Dependent Reasoning for the Experimental Group

The stepwise multiple regression method was used to explore whether scientific knowledge and scientific concept dependent reasoning would predict students' scientific problem solving. The first model indicated that the post-scientific concept dependent reasoning was the only significant factor for predicting their post-scientific problem solving performance ( $\beta = 0.73$ ,  $p < 0.000$ ). The second model indicated that the post-scientific concept dependent reasoning was the primary significant factor for predicting their problem solving performance ( $\beta = 0.390$ ,  $p = 0.002$ ), followed by post-scientific knowledge ( $\beta = 0.385$ ,  $p = 0.002$ ) (**Table 3**). Similar pattern was found for the retention-scientific problem solving, the first model indicated that retention-scientific concept dependent reasoning was the only significant predictor for retention-scientific problem solving ( $\beta = 0.745$ ,  $p < 0.000$ ). The second model indicated that the retention-scientific concept dependent reasoning was the primary significant factor for predicting their problem solving performance ( $\beta = 0.519$ ,  $p < 0.000$ ), followed by retention-scientific knowledge ( $\beta = 0.260$ ,  $p = 0.031$ ) (**Table 3**).

### Experimental Group's Students' Laboratory Scientific Problem Solving Performance

The repeated measures of ANOVA were conducted to examine the effect of the five problem solving tasks on the problem-solving performance across six dimensions, known knowledge, methods, explanations for a method, experimental design, estimating the experimental results, and assessment to given results. Results indicated that

**Table 4.** The Repeated measure of ANOVA in students' problem-solving task performance from task 1 to 5 for the experimental group

	Mean	SD	F value of repeated measures ANOVA	Post-hoc comparisons
Identify known Conception				
Task 1	0.38	0.24	57.77*** (0.000)	2>1 (0.000), 2>3 (0.000), 2>4 (0.000), 2>5 (0.000), 3>1 (0.000), 3>4 (0.002), 3>5 (0.022), 4>1 (0.000), 5>1 (0.000)
Task 2	3.23	1.58		
Task 3	1.64	1.11		
Task 4	1.12	0.72		
Task 5	1.14	0.95		
Provide Solutions				
Task 1	0.62	0.42	38.40*** (0.000)	2>1 (0.000), 2>3 (0.000), 2>5 (0.000), 3>1 (0.000), 3>5 (0.000), 4>1 (0.000), 4>3 (0.009), 4>5 (0.000)
Task 2	1.86	0.49		
Task 3	1.36	0.74		
Task 4	1.77	0.71		
Task 5	0.65	0.94		
Evaluate Solutions				
Task 1	0.53	0.34	49.83*** (0.000)	2>1 (0.000), 2>3 (0.000), 4>1 (0.000), 4>2 (0.000), 4>3 (0.000), 4>5 (0.014), 5>1 (0.000), 5>2 (0.001), 5>3 (0.000)
Task 2	0.90	0.40		
Task 3	0.61	0.36		
Task 4	1.55	0.57		
Task 5	1.29	0.61		
Design and Perform Experiment				
Task 1	0.48	0.33	50.26*** (0.000)	2>1 (0.000), 2>3 (0.000), 3>1 (0.000), 4>1 (0.000), 4>3 (0.000), 5>1 (0.000), 5>3 (0.000)
Task 2	2.71	1.04		
Task 3	1.72	1.29		
Task 4	2.92	1.07		
Task 5	2.89	1.49		
Evidence Based Explanations				
Task 1	0.47	0.63	47.29*** (0.000)	2>1 (0.000), 2>3 (0.000), 3>1 (0.000), 4>1 (0.000), 4>2 (0.002), 4>3 (0.000), 4>5 (0.006), 5>1 (0.000), 5>3 (0.000)
Task 2	2.29	1.04		
Task 3	1.78	1.44		
Task 4	3.16	1.69		
Task 5	2.56	1.34		

the five different tasks have a statistical significant effect on the problem-solving performance across all six dimensions (Table 4). The post hoc showed that the mean score of the 1<sup>st</sup> task is significantly lower than that of the 2<sup>th</sup> to 5<sup>th</sup> tasks across all six dimensions. The problem-solving performance of the 1<sup>th</sup> to 5<sup>th</sup> tasks fluctuated but revealed a significant progress as compared to the 1<sup>nd</sup> task.

## DISCUSSIONS

Our results demonstrated that the problem solving group performed significantly better than the traditional hands-on learning group on their immediate and retention performance of scientific problem solving. The possible explanation is that the problem solving tasks were developed and modified from many previous theories proposed in problem solving studies (Chua et al., 2016; Gick, 1986; Hmelo-Silver, 2004, 2007; Kirschner et al. 2006; Simon, 1978). The design of problem solving task required each learner to conduct the following cognitive processes on an individual basis except when performing the experiment: identifying known conceptions - students need to search prior domain knowledge from memory which might help solve the problem; identifying the possible factors causing the proposed question in order to help them solving the problem; providing more than two possible solutions to solve the problem solving task with proposed steps and strategies; evaluating their own solutions and deciding which solution is more applicable with explanations; performing the experiment according the most applicable design; answering a set of questions designed to see whether students were able to interpret the data and results with explanation. Our study demonstrated that well-designed and theory-based design problem solving tasks indeed successfully fostered their problem solving performance which is consistent with previous studies involving web-based biological and chemistry problem solving learning (She et al., 2012; Yu et al., 2010). We also went one step beyond our previous studies, insofar as this study actually required students to design and perform a real experiment in a laboratory in order to test and prove their solutions. That is, they had to conduct the experiment to see whether or not their best solution would actually work, rather than just generating more than

two solutions and evaluating those solutions conceptually. Our results further demonstrated that the inclusion of problem solving learning in the normal classroom learning for the middle school students was considered suitable and promising. This conclusion is also supported by several previous studies that found that problems with more than one solution can help students to develop their problem solving strategies (Klegeris et al., 2016; Mann et al., 2016; Tao, 2001). Some previous studies suggested that successfully solving a problem requires certain skills and abilities, such as the ability to understand the problem, the skill to apply and synthesize prior knowledge about the problem, the ability to make decisions about how to proceed, the knowledge of how to access the measures taken in the resolution processing, and being able to analyze the results (Harskamp & Ding, 2006; Hmelo-Silver, 2007; Maloney, 1994), all of which we include in our design to scaffold students' learning. One possible argument might arise that the problem solving group outperformed the traditional hands-on group because the problem solving group has taken two classes and traditional hands-on group has taken one class period. However, the control group receives six more lectures than did the experiment group. Due to such limitations as both group receiving different amount of hands-on classes and lectures, further research might be needed for clarification.

Our findings provide convincing evidence that the problem-solving learning group performed significantly better than the traditional hands-on learning group on their immediate and delay scientific knowledge performance. It indicated that receiving six problem solving tasks would efficiently promote students' science concept construction as compared to the traditional hands-on learning even though traditional hands-on learning group received six more traditional lecture classes than the problem solving group. This is also supported by Tao's (2001) study that found problems with multiple solutions can help students to develop their understanding of physics concepts. Previous studies suggested that learning to solve problems successfully in scientific domains, such as physics, requires understanding prior conceptual knowledge (Hambrick & Engle, 2003; Lucangeli, et al., 1998). Problem solving would enhance students' ability to reorganize their prior scientific knowledge and help them to consolidate their knowledge efficiently into their long term memory. This supports the idea of the construction of a problem representation, in which certain features of the problem may activate and link knowledge in memory (Kintsch & Greeno, 1985; Kirschner, 2006; Wang et al., 2013). The schema for that particular type of problem may then be activated and reorganized. As they go through problem solving tasks each semester, they are not just promoting their problem solving abilities; they are also developing better understanding of science knowledge. Our study provides evidence of problem solving indeed promotes students' domain specific knowledge, which was unclear before.

Our findings demonstrated that the problem solving group outperformed the traditional hands-on learning group on both immediate and retaining performance of scientific concept dependent reasoning involving physical science through receiving six times of problem solving. It is consistent with a previous study that reported problem based structure instruction can develop students' scientific reasoning habits and problem solving skills (Becerra-Labra et al., 2012). Our design requires students to search their prior knowledge for information relevant to the new problem, identify the possible factors relevant to the proposed question from their long-term memory, develop two possible solutions, and evaluate possible solutions, all of which heavily involves reasoning ability. This supports the previous study that reasoning pertains to the process of drawing conclusions from principles and from evidence (Wason & Johnson-Laird, 1972), moving on from what is already known to infer new conclusions and to evaluate a proposed conclusion. Our design of problem solving tasks prompts each individual student to use their scientific reasoning throughout the process, which is why the problem solving group performed significantly better than the traditional hands-on learning group on their scientific concept dependent reasoning.

Our stepwise regression results indicated that the best predictor for immediate scientific problem solving performance was their immediate scientific concept dependent reasoning performance and followed by their immediate scientific knowledge. In addition, the best single predictor for delayed scientific problem solving performance was delayed scientific concept dependent reasoning performance and followed by their delay scientific knowledge. Previous studies have reported reasoning is strongly correlated with problem solving (Chang, 2010; Lee & Jeon, 1998; Sonnleitner et al., 2013), however, our results move one step further to indicate that scientific reasoning is highly correlated with problem solving and also is the best predictor for problem solving. Our result further confirms that scientific concept dependent reasoning is critical for physical science problem solving. Moreover, our results somehow resemble the report of Voss et al. (1983) that domain-specific knowledge was the best predictor of performance in solving ill-structured problems, except that our study found that scientific knowledge is a second good predictor for students' problem solving performance. Our study further implies that scientific concept dependent reasoning is a better predictor than scientific knowledge for problem solving regardless of immediate or delayed performance.

Within the problem solving group (experimental group), our results indicated that the students' problem-solving performance reached a statistical significant progress across all of the five dimensions including identify known conceptions to facilitate solving proposed problem, provide more than two possible solutions, evaluate their own solutions, design and perform the experiment according to the most applicable design, and challenge students'

evidence based explanations according to their results. The problem-solving tasks in this study provided students with recurrent opportunities for five tasks across a semester and significantly improved students' problem-solving performance. It clearly indicated that problem solving instruction can effectively promote students problem solving ability after a practice task and formal 1<sup>st</sup> task learning. In other words, students' problem solving ability rise up sharply right after two tasks' problem solving learning. Though it fluctuated from 2<sup>nd</sup> to 5<sup>th</sup> task which might due to the content difficulty are varied from task to task. However, the mean score of 1<sup>st</sup> problem solving performance was at the lowest point comparing to the latter tasks. The results were in line with some studies showing that problem-solving can be efficient under an instructional design with well-constructed scaffolds (Kim & Hannafin, 2011; She et al., 2012).

In summary, when given repeated opportunities to learn by problem solving, students can reason based on their prior knowledge to connect their past experiences with new situations and can engage in the scientific practices of questioning, inferring, making inquiries, evaluating and explaining in order to learn content knowledge. This study demonstrated empirically that well-designed problem solving teaching indeed improved students' performance in terms of content knowledge, reasoning and problem solving and thus suggests that problem solving teaching is suitable for inclusion in the normal curriculum for middle school students.

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## APPENDIX I

## Examples of Problem solving and traditional hand-on learning

	Problem solving	Tradition hands-on learning
Topic	<ul style="list-style-type: none"> <li>Please generate two possible solutions in order to identify the rank of chemical activity for three unknown elements.</li> </ul>	<ul style="list-style-type: none"> <li>Observed the changes of four elements and two oxides after heating.</li> </ul>
Related materials were given	<ul style="list-style-type: none"> <li>Carbon, three unknown elements (X, Y, Z) powders and their oxides (XO, YO, ZO) powders.</li> </ul>	<ul style="list-style-type: none"> <li>Four elements (Magnesium, copper, zinc, carbon) and carbon dioxide, copper oxide</li> </ul>
Instructional steps	<p><i>Step1. identify known conceptions to facilitate solving proposed problem</i></p> <p>Please provide what are the possible concepts and knowledge that you have learned can help you to identify the rank of these elements chemical activity</p> <p>Step 2. provide more than two possible solutions</p> <p>What are the two solutions you can use to classify the rank of these elements chemical activity?</p> <p>Step3. Evaluate their own solutions</p> <p>Please evaluate each solutions you provided to determine which one is more workable and plausible than the other and with your explanations.</p> <p><i>Step 4 perform the experiment according to the most applicable design</i></p> <p>Please provide the most applicable design and perform the experiment.</p> <p><i>Step 5. challenge students' evidence based explanations according to their results</i></p> <p>We provide a real experiment results for students and ask students to provide their explanation and conclusions according to their experiment evidence.</p>	<ul style="list-style-type: none"> <li>Follow laboratory book step by step</li> </ul> <p>Step 1. Use alcohol burner to heat a scoop holding a slice of magnesium, and observe its changes.</p> <p>Step2. Use alcohol burner to heat a scoop of copper powder, and observe its changes.</p> <p>Step3. Use alcohol burner to heat a scoop of zinc powder, and observe its changes.</p> <p>Step4. Use alcohol burner to heat a scoop of carbon powder, and observe its changes.</p> <p>Step5 Use alcohol burner to heat a test tube with both carbon and copper oxide, and observe its changes.</p> <p>Step 6 Use alcohol burner to heat a scoop holding a slice magnesium then put into a jar with carbon dioxide, and observe its changes.</p> <p>Step 7. Compare the rank of chemical activity for these four elements: carbon, copper, magnesium, and zinc according to the experiment results.</p>

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