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Students' Mental Models of Solid Elasticity: Mixed Method Study

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ABSTRACT

A mental model (MM) is an internal representation of students' conceptual understanding. Currently, students have still had difficulties in explaining the physical state of elasticity of solid materials, at sub-microscopic level. These difficulties call for this research. Through a mixed method, the study aimed to reveal the development and differences of students' mental models after physics learning with problem - based learning (PBL) and conventional methods. Indicators of students' mental models were adapted from SMD model. Findings suggested that the PBL resulted in more MM, whilst conventional classes emerged MM on the elastic and plastic objects. Meanwhile, the lowest MM achievements ware Hooke's Law for the PBL, and series and parallel springs for the conventional class. N-Gain values of the students' mental models at PBL and conventional classes were found to be 0.64 and 0.43 respectively. On the other hand, mental model scores of the PBL learning model was higher (23.77%) than those of the conventional learning model. Thus, it can be concluded that the PBL learning model is effective in improving the students' mental models of physics. This research recommends that students' understanding of physics concepts should be increased at macroscopic and sub-microscopic levels.

Keywords: Mental models, Problem-based learning, Physics learning, Solid elasticity.

INTRODUCTION

One of the core objectives of physics learning is to enable students to learn related concepts that they face every day and to associate physical facts with the physics concepts (Pendrill, 2020). Physics concepts are closely related to learning process (Steenkamp, Rootman-le Grange, & Müller-Nedebock, 2019). Therefore, a teacher should give opportunities for students to develop the concepts through a learning process (Bigozzi, Tarchi, Fiorentini, Falsini, & Stefanelli, 2018). Conceptual understanding necessities to construct abstract concepts and more complex knowledge (Supasorn, 2015). Recently, psychology and science researchers have collaborated in revealing how individuals develop their conceptual understanding and manage their internal abilities (Zarkadis, Papageorgiou, & Stamovlasis,

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2017). Internal abilities or representations, which are cognitive structures, help individuals develop their mental models. The abilities also refer to the process of understanding certain phenomena, evaluating a mental process, and determining the extent of obtained information (Hung, Xu, & Lin, 2020).

A mental model (MM), which is defined as a representation of individual knowledge (van Schijndel, van Es, Franse, van Bers, & Raijmakers, 2018), acts as an analog structure of a situation or a process (Oh & Park, 2014). MM is associated with a structure of knowledge, which consists of coherent elements to explain phenomena (Pasco & Ennis, 2015). A mental model is functionally similar to a computer simulation, which allows students to process knowledge in predicting a result (Liu, Lin, & Tsai, 2020). A mental model could also provide reliable information about students' conceptual frameworks of learning physics (Shen, Tan, & Siau, 2019). The model developed in a student's mind could inform teacher about his/her knowledge structure (S. K. Park & Oh, 2013).

A mental model plays a vital role in a learning process (Gary & Wood, 2016) in which a teacher guides his/her students to independently construct their knowledge through their mental models (Akaygun, 2016). Physics scientists such as Kelvin, Boltzmann, and Maxwell have applied mental models since the 19th century (Johnson-Laird, 2013). Some researches, which have not used any particular learning models/strategies, have reported that students' mental models are different from physics content and/or topics, such as heat conductivity (Chiou & Anderson, 2010), mechanical wave (Hrepic, Zollman, & Rebello, 2010), heat convection (Chiou, 2013), light, energy, and angular momentum (Didiş, EryIlmaz, & Erkoç, 2014), friction force (Canlas, 2019), electromagnetic (Claassen, Bostrom, & Timmermans, 2016), concept of force and velocity (Johnson-Glenberg, Megowan-Romanowicz, Birchfield, & Savio-Ramos, 2016), modern physics (Korhasan et al., 2016) and electrical circuit (Lin, 2016).

A mental model, which is one of the main objectives of physics learning (Stains & Sevian, 2015), necessitate to use a learning model (e.g., Problem-Based Learning-PBL) for constructing students' conceptual understanding (Askell-Williams, Murray-Harvey, & Lawson, 2007). PBL could be used to improve students' conceptual understanding in discussions and individual learning (Akçay, 2009). Limited information has been found on how to empower students' mental models through learning models, such as the characteristics of mental model proposed by (E. J. Park & Light, 2009) based on 5 types of MM; 7 types of MM (Chiou, 2013), 3 types of MM (ÖZCAN, 2013), 6 types of MM (Didiş et al., 2014), and 3 types of MM (Altan Kurnaz & Eksi, 2015). A surface, matching, and deep (SMD) type of mental model is more straightforward than other types of MM in terms of the evaluation process. Even if students can answer correctly physics concepts, they are unable to give reasons or provide scientifically incorrect reasons with the surface category. If students can answer correctly by giving explanations or reasons correctly, it is defined as a matching category. If students can answer correctly and provide correct explanations by, providing scientifically correct answers for predictive questions, it falls into a deep category (Ifenthaler, 2006).

Have reported that medical students, who were exposed to the use of PBL and traditional learning methods, showed different mental models (Lycke, Grøttum, & Strømsø, 2006). They studied aspects of the mental models including knowledge construction, knowledge intake, knowledge utilization, and cooperation. Such indicators of mental model significantly differ from the Ifenthaler's SMD mental model (2006). Inquiry model could better improve students' mental models electricity circuits as compared to the traditional learning method (Korganci, Miron, Dafinei, & Antohe, 2015). The implementation of the PBL offered opportunities for each member of the group to obtain new skills and improve their abilities, as well as developing their mental models (Yew & Goh, 2016).

The results of the study proved that the use of PBL, which enabled small groups of students to negotiate and exchange their knowledge during the learning process, resulted positively in developing students' mental models (J R Batlolona, Singerin, & Diantoro, 2020). Students discuss any to find the appropriate answers so that the students with low abilities could also improve their learning capacities (Dring, 2019).

Material elasticity, which is an important part of physics and engineering programmes (Rubinstein & Panyukov, 2002), protects human's limbs and human activities. Because the mental model potentially explains the physical elasticity of solid materials at macroscopic and sub-microscopic levels, students are able to understand and explain how force influences the states of particles or molecules. To this extent, students are only able to explain the state of an elastic material at a macroscopic level, but unable answer at sub-microscope level or conditions/states of the particles. Thus, PBL bridges macroscopic level to sub-microscopic one. Any PBL provides opportunities for mastering macroscopic and microscopic levels, for example student orientation to problems. In this phase, a teacher gives questions given student knowledge.Through a physics case, questions can be raised from simple to complex levels. The teacher asks step by step by bridging macroscopic level to sub-microscopic one (Batlolona, 2017). Hence, this research aimed to reveal the development and differences of students' mental models after physics learning with PBL and conventional methods.

METHODS

a) Research Design

This research employed a mixed-method with embedded design to explore students' mental models of elasticity after learning with PBL and conventional methods. This design aims to obtain quantitative and qualitative data simultaneously handle secondary data (qualitative data) that can support primary data (quantitative data). Hence, qualitative and quantitative data complement each other to form a better understanding of the problems. This study collected qualitative data after the experiment to support experimental studies (Creswell, 2012). Quantitative data were obtained through a quasi-experimental research, while qualitative data were collected through interviews. The PBL and conventional methods were the independent variables while the mental models were the dependent variables.

b) Population and Sample of the Research

The research population was all tenth grade students from *Natural Sciences* programs of high schools. The sample of this research comprised of 77 students randomly drawn from SMA Negeri (Public Senior High School) 8 Malang, Indonesia. The experimental group (n=38) used the PBL learning model, while thecontrol group was instructed with conventional method. Physics learning took three hours a week for all students. The teaching interventions totaly lasted 6 weeks (18 class hours) for the PBL and conventional methods. Conventional method covered several varied learning methods such as lectures, assignments, and discussions. PBL method embraced the following steps: (i) focusing students' attention on problems and formulating hypotheses, (ii) organizing student learning, (iii) conducting individual or group investigations, (iv) creating and presenting students' works, and (v) evaluating students' problem-solving steps (Arends, 2012).Topics under investigation included elastic and non-elastic objects, stress, strain and Young's modulus, Hooke's law and parallel series spring arrangement.

c) Instrument and Procedure

A mental model test (mental model instrument/MMI) with 10 structured questions was used for data collection (see Table 1 sample questions). The researchers developed the instrument and invited physicists and physics educators from Universitas Negeri Malang to ensure its validity. Before doing the real research on the experimental class in SMA Negeri 8 Malang City, the MMI was pilot-tested with 125 students from high schools in Malang City, such as SMA Negeri 2 Malang, SMA Negeri 4 Malang, SMA Negeri 5 Malang and SMA Santa Maria of Malang city. The results showed that the instrument had a high validity (0.72) and reliability (0.94). The mental model test was modified from Ifenthaler's rubric (2006) which indicates three kinds of mental models. Firstly, if students correctly answer a dimension, they have a surface type of mental model (S). Secondly, if they correctly answer two dimensions, they have a matching type of mental model (M). Lastly, if they correctly answer all dimensions, they have a deep mental model (D).

This research followed the subsequent procedure: (i) testing MMI with eleventh-grade students in several high schools in Malang, until a valid and reliable instrument was obtained, (ii) coordination with schools, and physics teachers to discuss planned learning activities, research procedures, and prepare tools and materials for practice, (iii) randomly assigning the experimental (PBL) and control conventional) groups, (iv) the pretest to the groups, (v) carrying out the teaching interventions in the experimental and control groups and observing learning activities models, (vi) administering the posttest to the groups, and (vii) conducting interviews to confirm the students' works on each topic and their MM results.

d) Data Analysis

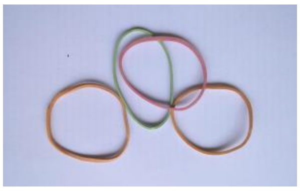
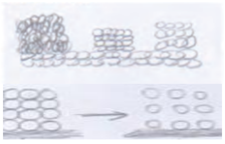
Qualitative data were descriptively analyzed in this research. The students' developmental levels of MM were evaluated by N-Gain normalization <g> (Hake, 1999), while quantitative data were analyzed through the covariance (ANCOVA) test in SPSS 23™. Before running statistical analysis, prerequisite tests, i.e., normality and homogeneity tests were done point out normal distribution. The results revealed normal and homogeneous distributed data.

FINDINGS

This section presents the students' mental models of solid elasticity after physics learning with PBL and conventional methods.

Table 1. *The students' answers and categories to the questions*

Questions	Students' Answers	Categories
1. Please pay attention to the picture below that displays a new type of airplane (Boeing 737-900ER) released by Lion Air in 2016. Its weigh is 9,550 tons and passenger capacity is 213.  (Zhang & Yang, 2015) [1] Why are not airplane tires made from iron, wood, or flexible tires filled with air? [2] Explain why airplane tires are made of solid rubber! [3] Describe what happens to the molecules of the airplane tires when the planes are landing!	**S2:** [1] Airplane tires are not made of iron, wood, or flexible tires filled with air because tires made of such materials become high risks as the planes land or move on the runway. [2] No answer [3] No answer	Surface

2. Please pay attention to the following picture that indicates rubber bands with a 5-cm diameter.  [1] What happens if the rubber bands are pulled? [2] Explain why! [3] How will the molecules of the rubber bands react when they are forced.	**S1:** [1] When pulled, the rubber bands elongate (deformation). [2] It is due to the elastic property of rubber bands so when they receive an external force (pull); then it will deform by the amount of force given to them. [3] No answer	Matching
3. Please pay attention to the picture of a 200m suspension bridge below that consists of a tower (1) and suspender cables (2).  (Seible, Dazio & Restrepo, 2005) [1] How is the condition of the suspender cables on day and night time? [2] Please explain why the suspender cables are made of steel! [3] Please describe the suspender cables' particles on day and night time.	**S23:** [1] On daytime, the suspender cables will expand or be more flexible, while they harden at night. [2] Because steel has a hard structure so that the suspender cables could return to their original form even though they have reached the melting point due to the bridge loads [3] Microscopic Condition  Suspender cables' particles at daytime 	Deep

As seen from Table 1, the students' responses to the question reached the Deep level under the excellent qualification.

The results of the post-test revealed that the highest MM scores appeared at each learned topic for the PBL and the topic of elastic and plastic objects for the conventional class. The lowest achievement emerged the topic of Hooke Law for the PBL class and the topic of series and parallel springs for the control class (see Figure 1).

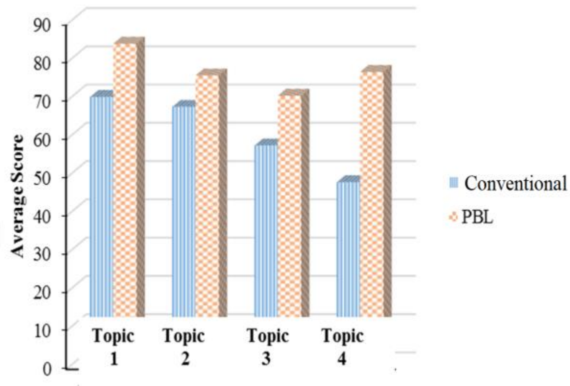


Figure 1. Mean scores of the students' MM on each topic
Information:
Topic 1 = Elastic and plastic objects
Topic 2 = Tension, strain, and young modulus
Topic 3 = Hooke Law
Topic 4 = Series and parallel springs

The results indicated that the students' pretest scores of mental models were mostly categorized under the matching and surface levels. Also, some students did not even provide any answers at all. After the treatments, the students could achieve better. However, frequencies of the students' responses labeled under the 'deep mental model' were higher in the experimental (PBL) class than the control (conventional) one. As shown from Figure 2, the students reached the 'Deep' level or the topic of series and parallel springs

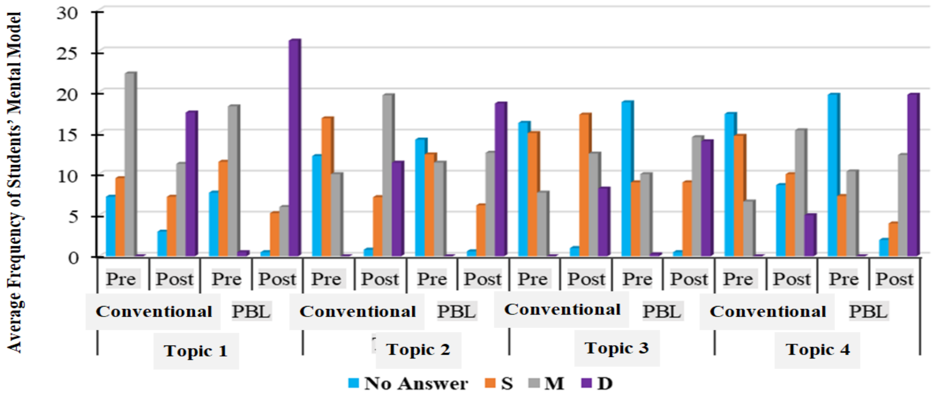


Figure 2. Frequencies of the experimental and control groups' mental models

Table 2 describes the pretest and post-test scores of the students' mental models, as well as their N-Gain values.

Table 2. *Descriptive results of the students' pretest, post-test, and N-gain values*

Descriptive statistics	PBL Group		Conventional Group	
	Pretest	Post-test	Pretest	Post-test
Highest Score	48.1	85.4	45.9	70.9
Lowest Score	8.31	62.6	10.4	52.1
Mean	31.8	76.4	32.1	61.7
N-Gain	0,64		0,43	

As can be seen from Table 2, the lowest pretest scores of the experimental and conventional classes were 8.31 and 10.4 respectively. The mean difference between them was 2.09. The highest post-test score of the experimental class (PBL group) was higher than that of the conventional one. Similarly, the N-Gain value of the PBL group (0.64) was higher than that of the conventional one (0.43).

Table 3 presents the results of single ANCOVA test for the students' mental models.

Table 3. *The results of single ANCOVA test*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Experimented Model	4147.822[a]	2	2073.911	63.612	.000
Intercept	46152.420	1	46152.420	1415.617	.000
XMental	1.581	1	1.581	.049	.826
Model	4143.947	1	4143.947	127.106	.000
Error	2412.572	74	32.602		
Total	372984.914	77			
Corrected Total	6560.394	76			

a. R Squared = .632 (Adjusted R Squared = .622)

As seen from Table 3, there were significant differences between the experimental and control groups' mental models. Table 4 exhibits the significant differences between them through the results of LSD test.

Table 4. *The results of LSD test*

Model	XMMental	YMMental	Difference	MentalCorr
PBL	31.8207	76.4178	44.5971	76.416
Conventional	32.0865	61.7404	29.6539	61.742

As seen from Table 4, mean score of the experimental group's mental models was higher than that of the conventional one. In addition the PBL learning was more effective at improving the students' mental models than the conventional one.

DISCUSSION and CONCLUSION

Studies of a solid elasticity are essential for physics and engineering fields (Pestka, 2008). The students' responses to the questions showed an improvement in their knowledgeof the solid elasticity at sub-microscopic level. Their answers also indicated different types of mental models. It means that the students' knowledge developed from the surface level to the deep one. Teachers can use these results as an evaluation tool to reveal students' conceptual maps and/or conceptual growth (Richardson, 2007).

The findings showed that the students have still faced difficulties answering questions related to Hooke's Law and series and parallel springs. This may result from students' difficulties at describing a particle on series or parallel springs and understanding different cross-sectional areas in Hooke's Law (Batlolona et al., 2019). Further, this may stem from any learning strategy that do not facilitate students' problem-solving skills (Xiao, Barnard-Brak, Lan, & Burley, 2019). The students cannot understand the concepts or principles and rules of physics due to inability to understand the questions, and a lack of motivation (Salta & Koulougliotis, 2020)

The results also indicated that most of the students in the PBL (experimental) class reached the deep understanding level of elastic and plastic objects. This may come from the feature of the PBL class, which gave the students an opportunity to develop their thinking processes. Thus, encouraging them to think deeply and independently enabled the experimental group construct their knowledge. The PBL also helped them develop their understanding of physics (Fidan & Tuncel, 2019). Even though their pre-existing knowledge fell into the macroscopic level, the PBL learning process assisted them in greatly obtaining the sub-microscopic one.

N-Gain values revealed that overall N-Gain value of the experimental group's mental model indicators was higher (0.21) than that of the control group. Similarly, the results of LSD test also showed that the PBL was more effective at improving the students' mental models than the conventional learning model (Lozano, Gracia, Corcho, Noble, & Gómez-Pérez, 2015). PBL learning model could also assist students in developing their mental models in either group or individual learning to solve problems (Scott, 2017). Additionally, PBL is more efficient at independently or collaboratively facilitating student learning as compared to the conventional learning method (Overton & Randles, 2015).

Collaboration allows students to communicate better and achieve a higher level of cognitive skills (Carter, Richards, Hotopf, & Hatch, 2019). PBL, as a learning model, facilitates the development of students' higher order thinking and problem-solving skills (Phungsuk, Viriyavejakul, & Ratanaolarn, 2017). It also assists students in learning scientific content/knowledge based on the relevant curriculum (Yeo & Tan, 2014). Thereby, PBL is different from the traditional learning method, in which only direct students to memorize knowledge. Because collaboration is useful for constructing knowledge, solve problems in their groups. Hence, students have an opportunity to express their ideas, widely and deeply, and negotiate their solutions in their groups. Collaboration also elaborates their physics knowledge of elasticity in macroscopic and sub-microscopic levels. Further, it equips students with high academic abilities and completes their academic learning.

The present research revealed that employing a mixed method generates different results from, previous researches (Lin, 2017). Research findings suggested that the PBL learning model improved the students' mental models of elasticity. N-Gain values showed that the PBL group performed better achievement than the conventional one. However, both of the groups (PBL and conventional learning) have still faced difficulties in studying Hooke's Law, and series and parallel springs. In addition, the results also showed that mean score of the PBL group was higher than that of the conventional group. The PBL was more effective at improving the students' mental models than the conventional learning method. This research suggests that students' understanding of physics concepts at macroscopic and sub-microscopic levels should be increased. The implementation of PBL is promising to enhance students' abilities to achieve the Surface, Matching, Deep levels. Future research should focus on how to improve students' conceptual frameworks/scaffolds of physics for relevant variables and/or macroscopic and sub-microscopic levels.

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