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DO PHYSICS TEXTBOOKS PRESENT THE IDEAS OF THOUGHT EXPERIMENTS?: A CASE IN INDONESIA

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ABSTRACT

This study sought to check and evaluate whether or not thought experiments presented in the Indonesian physics textbooks can be used as tools to transfer scientific knowledge. This was a descriptive study using Indonesian physics textbooks as the primary sources of data. In this study, we analyzed thirty (30) physics textbooks from Grades 10 to 12 which are widely used both by teachers and students. The results showed that majority of physics textbooks did not mention about thought experiments. Only 6 physics textbooks presented thought experiments at a satisfactory level. The number of physics textbooks that described thought experiments in fair and poor levels are 9 and 5 respectively. The study concludes that Indonesian physics textbooks published from 2009 to 2017 generally lack thought experiments. Many authors of these Indonesian physics textbooks ignored or inadequately present thought experiments. Moreover, 70% of thought experiments mentioned in the physics textbooks were in the fair and poor levels. So, in general, thought experiments presented in the Indonesian physics textbooks cannot be used as an introduction in transferring scientific knowledge to science students.

Keywords: Indonesia, physics textbook, thought experiments

INTRODUCTION

Thought Experiment (TE) in the field of physics plays important roles in constructing scientific theories. Many famous scientists used TEs either to represent their views in formulating a new theory or to show the weakness of an existing theory as well as to destroy a common theory (Brown, 1986; Duhem, 1990; Reiner, 1998; Cooper, 2005). Without TEs, the theory of relativity would not have been possible as Einstein and Infeld (1938) argued that the ideal experiments created by thought greatly helped them in formulating the theory of relativity which is possible by simple methods. Due to its essential role, some researchers have been paying attention to the TEs in the area of science education, especially physics. There are several studies that have explored the role of TEs in the teaching and learning physics. For example, the study of Lattery (2001) indicated that the use of TEs creates a fruitful discussion and even helps students generate well-rationalized hypothesis for their experiments. Other studies showed that TEs could improve active engagement and may help students to mentally construct (Lattery, 2001; Klassen, 2006; Velentzas & Halkia, 2013). Furthermore, TEs can help the students recognize the scientific thinking and understand physics concepts better (Gilber & Reiner, 2000; Reiner & Gilber, 2004; Velent-

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zas et al., 2007; Ince et al., 2016). TEs can also expose students' hidden reasoning and improve students' inquiry skills through thinking processes (Clement, 2009; Kosem & Ozdemir, 2014). Some researchers also suggest that physics teachers and even in-service physics teachers familiarize their students with TEs when teaching physics at school (Reiner & Burko, 2003; Galili, 2009; Asikainen & Hirvonen, 2014). Thus, TEs seem to be very important especially in the teaching and learning of physics.

Trying to understand how TEs are presented in the general physics textbooks, Gilbert & Reiner (2000) studied and focused on three popular physics textbooks. One of them, the *Understanding Physics for Advanced Level* written by Breithaupt was intended for 16-18 year-olds in high schools in England and Wales. The other two, *Physics (2nd edition)* written by Ohanion and *Conceptual Physics (7th edition)* written by Hewitt are widely used in first-year university courses in the USA and elsewhere. The results show that the popular physics textbooks often miss the opportunity to introduce TEs even though there are various reasonable opportunities to do so. Moreover, TEs in those textbooks often transform into thought simulations. Gilbert & Reiner (2000) argued that the writers of these popular physics textbooks may not understand the actual potential of using TEs. In fact, TEs can be a fruitful approach to enhance students' cognitive engagement in the learning process.

On the other hand, Velentzas et al. (2007) specifically investigated the presence of TEs on the theory of relativity and quantum mechanics in both physics textbooks and popular science books. There were ten textbooks and fifteen popular science books in their study. The physics textbooks that they analyzed were mostly from university books and only one Greek textbook from high school. The popular science books were addressed to the general public. The results showed that the authors of both physics textbooks and popular science books considered TEs as an essential tool in the presentation of the theory of relativity and quantum mechanics (Velentzas et al., 2007).

Although there have been studies that specifically examined TEs in physics textbooks, most of the textbooks were for university level. Analysis of school textbooks in relation to TEs has not been extensively conducted by the education community, whereas students need to be introduced to TEs early in the school. In this way, physics textbooks play a major role because physics teachers today still often teach physics based on the textbook (Levitt, 2002). The school textbooks are not only easily accessible but can also support each student's learning style (Ogan-Bekiroglu, 2007). Teachers should consider that students have their own learning style (Watson & Thomson, 2001; Denig, 2004) as well as thinking style (Watson & Thomson, 2001; Pintrich, 2002; Bancong & Subaer, 2013, 2015) in order teach physics.

Analysis of the content related to TEs in physics textbooks would provide a good indication showing how much of TEs are taught in the schools. In this study, we explored TEs present in the Indonesian physics textbooks and evaluated whether they are necessary or not to serve as a tool to transfer scientific knowledge to students. So, the research questions in our study were: (1) How frequent and what kind of TEs are present in Indonesian physics textbooks? (2) How did the authors present TEs in Indonesian physics textbook? (3) Can the TEs present in Indonesian physics textbooks be used as an introduction in transferring scientific knowledge?

METHODS

This research used the descriptive method to describe the real situation of TEs presented in Indonesian physics textbooks. In this study, 30 physics textbooks published and used from grade 10 to 12 in Indonesia were analyzed. Physics textbooks published by the Ministry of Education were the main focus (BSE physics textbooks). However, the analysis also was carried out on several physics textbooks which became available through government approval (Non-BSE physics textbooks). According to Mukaromah & Suparwoto (2016), there is no difference between the contents BSE and Non-BSE physics textbooks. The guidelines for selecting physics textbooks were: (1) written based on 2006 Curriculum or 2013 Curriculum; (2) widely used by teachers and students; and (3) published by well-known book publishers.

There were eight TEs evaluated in this study. These eight TEs were based on the content of standards of competencies from the Indonesian National Curriculum. The evaluation of TEs was done for both 2006, and 2013 curricula since some schools in Indonesia still use the old 2006 curriculum. The contents of TEs related to the standard competencies from Indonesian National Curriculum are shown in table 1.

Table 1. The content of TEs related to standard of competencies from Indonesian

No	Grade	Standard of Competencies		TEs
		2006 Curriculum	2013 Curriculum	
1	10	Analyzing the physical quantities of rectilinear motion with constant velocity and acceleration	Analyzing the physical quantities of rectilinear motion with constant velocity and rectilinear motion with constant acceleration.	Galileo's free fall
2	11	Analyzing the regularity of planetary motion in the solar system according to Newton's laws.	Analyzing the regularity of planetary and satellites motion in the solar system according to Newton's laws.	Newton's canon
		Analyzing the changes in the ideal gas state by applying the laws of thermodynamics	Analyzing the changes in the ideal gas state by applying the laws of thermodynamics	Maxwell's demon
3	12	Formulating the special theory of relativity for time, length, and mass, as well as equality of mass and energy that can be applied in technology	Explaining the phenomenon of changes in the length, time, and mass associated with reference frame, equality of mass and energy in the special theory of relativity	Galileo's relativity, Einstein's chasing a light beam, Einstein's magnet and conductor, Einstein's train, Einstein's twin paradox

In order to analyze the textbooks, Niaz et al. (2013) used three classifications: satisfactory, mention, and no mention. If the textbook provides information in detail, it becomes "satisfactory" classification, while if the textbook provides information in semi-detail, then it is "mention" classification. In our views, the classification of mention is too general and widespread. Therefore, we divided the classification of mention into two sub-categories: fair and poor. So, there are four classifications used in this study: satisfactory, fair, poor, and no mention.

The three criteria we used to classify TEs in physics textbooks were: (1) background; (2) performance; and (3) results. These criteria are related to each other in conducting TEs. In our opinion, the existence of performance and results without a background would cause students not know the history of TEs. Similarly, the existence of background and results without performance will cause the students do not recognize what TEs are. So, the following classifications used to analyze TEs in the Indonesian physics textbooks were: *satisfactory* – if TEs in physics textbooks meet all the criteria; *fair* – if TEs just meet two criteria; *poor* – if only one of the criteria is provided in the physics textbooks; and *no mention* – if the physics textbooks did not mention TEs at all.

RESULTS AND DISCUSSION

The analysis on TEs presented in the Indonesian physics textbooks resulted in three groups based on the grade. Table 2 shows the results of TEs for Grade 10.

Table 2. The Results of TEs in the Indonesian Physics Textbooks for Grade 10

No.	TEs	Indonesian Physics Textbooks									
		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
1	Galileo's free fall	F	S	F	P	N	N	N	P	N	S

S: Satisfactory; F: Fair; P: Poor; N: No Mention

Galileo's free fall

It is clear that only two of ten physics textbooks present the ideas of Galileo's free fall at the *satisfactory* level as shown in Table 2. In textbook A2, the author presented the background and performance of Galileo's free fall about the feather, and the paper dropped in a vacuum tube. The author presented the TE by assuming these objects will reach the bottom of the vacuum tube at the same time. The following is an example of TE of Galileo's free fall at the *satisfactory* level as shown in textbook A2.

Before Galileo's time, the most of the people believed in Aristotle's ideas that heavier objects would fall faster than lighter objects. In other words, the speed of falling an object is proportional to its weight. Galileo then opposed that idea and declared that all objects would fall with the same acceleration in the absence of air or other obstacles…….To strengthen his argument, he gave an ingenious experiment. Imagine in the space where air has been sucked, light objects such as feathers or a piece of paper held horizontally will fall with the same acceleration as other heavy objects. As we know that demonstrations in a vacuum like this did not exist in Galileo's time. Nevertheless, Galileo believed that air acts as an obstacle to very light objects that have a large surface……The results of this experiment show that all objects will fall with the same constant acceleration. For an object that falls from the rest, the distance traveled will be proportional to the square of time, $h \approx t^2$ (Sumarsono, 2009: 45-46)

Table 2 also shows two physics textbooks at the *fair* level. The authors presented Galileo's free fall in two ways. First, the authors explained the background and results of Galileo's free fall but did not provide the performance of that TE. Second, the authors explained the performance and result of Galileo's free fall but did not provide its background. Therefore, they cannot be used as an introduction in transferring scientific knowledge to students with the loss of one of three satisfactory criteria of TEs. The following is an example of TE of Galileo's free fall at the *fair* level as shown in textbook A1.

In Aristotle's day, people believed that falling objects would take time depending on the mass of the object. Aristotle argued that objects with a larger mass would reach the ground more quickly. This view is still widely considered true by today's society who do not understand it. Yet this view of Aristotle has been opposed by Galileo (1564-1642). He was a scientist who opened a new view of the importance of experimenting….. Galileo has conducted experiments on an object in the free fall. The results show that the time needed by falling objects does not depend on its mass but depends on the height. Is Galileo's view correct? The truth can be proven by your own experiment or mathematically.

$$h = Vo.t + \frac{1}{2}gt^2$$

$$h = 0 + \frac{1}{2}gt^2$$

$$t = \sqrt{\frac{2h}{g}}$$

(Handayani & Damari, 2009: 65)

Furthermore, two physics textbooks were describing Galileo's free fall at the *poor* level. In this level, the authors just described the result of Galileo's free fall without background and performance. Clearly, they cannot be used as an introduction to transport scientific knowledge due to the lack of the background and performance. Sadly, 40% of physics textbooks failed to present TE of Galileo in describing the theory of free fall. These physics textbooks provide free-fall equations with a few explanations.

Newton's Canon and Maxwell's Demon

Table 3 shows the result of TEs analysis in physics textbooks for Grade 11. It is clear that the physics textbooks did not mention Newton's canon and Maxwell's demon. In fact, there could have some opportunities to introduce them. For example, TE of Maxwell's demon can be introduced to support the molecule-kinetic theory and the second law of thermodynamics. This Maxwell's demon produced several conclusions that support the gas kinetic theory, and the second law of thermodynamics thus making these theories becomes more logical.

Table 3. The Results of TEs in the Indonesian Physics Textbooks for Grade 11

No.	TEs	Indonesian Physics Textbooks									
		B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
1	Newton's canon	N	N	N	N	N	N	N	N	N	N
2	Maxwell's demon	N	N	N	N	N	N	N	N	N	N

S: Satisfactory; F: Fair; P: Poor; N: No Mention

Galileo's Relativity

There are two physics textbooks that describe the Galileo's relativity at the *satisfactory* level as shown in Table 4. In textbook C9, for example, the authors gave a brief background of Galileo's relativity then presented it in the form of a child riding a cart of constant speed, and throwing the ball vertically up. The authors illustrated the trajectory of the ball based on two observers in different reference frames as shown in figure 1.

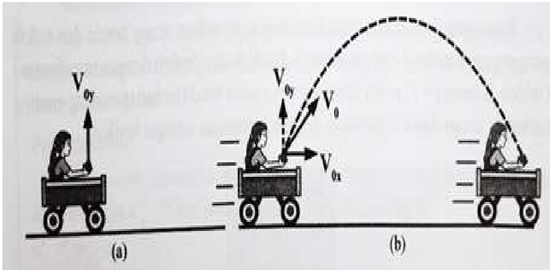

Figure 1. The difference of trajectory of two observers in different reference frames, (a) a reference frame with constant velocity (b) a silent reference frame (Sunardi et al., 2016)

Finally, the authors described the results of Galileo's relativity in the form of mathematical equations with some explanations. This is an example of TEs at the *satisfactory* level where there are the background, performance, and results of TEs. However, there are still three TEs presented at the *fair* level and half of the physics textbooks analyzed did not mention the idea of Galileo's relativity when explaining the theory of relative speed.

Table 4. The results of TEs in the Indonesian physics textbooks for Grade 12

No	TEs	Indonesian Physics Textbooks									
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
1	Galileo's relativity	F	N	S	F	N	F	N	N	S	N
2	Einstein's chasing a light beam	N	N	N	N	N	N	P	N	N	N
3	Einstein's magnet and conductor	N	N	N	N	N	N	N	N	N	N
4	Einstein's train	N	N	P	N	P	P	N	N	N	S
5	Einstein's twin paradox	S	N	P	N	N	N	P	N	P	N

S: Satisfactory; F: Fair; P: Poor; N: No Mention

Einstein's Chasing a Light Beam

Einstein's chasing a light beam was the first TEs by Einstein in constructing the theory of relativity. This TE aims to test Maxwell's theory indicating a light wave in a vacuum that always propagates at the same speed with respect to the ether. Einstein then gives his TE as follows.

"If I pursue a beam of light with the velocity c (velocity of light in a vacuum), I should observe such a beam of light as an electromagnetic field at rest though spatially oscillating. There seems to be no such thing, however, neither on the basis of experience nor according to Maxwell's equations" (Einstein, 1949:53)

In this TE, Einstein assumed that the speed of light would be 0 when the observer is able to catch the light. Similarly, a water skier will see a stationary wave of water when he is able to move with the water. The results of this TE emphasize that light propagates in a vacuum without a medium like a bullet fired from a rifle. Therefore, the speed of light is not always constant but depends on the reference frame of the observer.

However, none of the physics textbooks above described TE of Einstein's chasing a light beam at the *satisfactory* level. Unfortunately, this TE is very potential to be explained at the beginning of the relativity theory showing that the speed of an object is not absolute but depends on the observer' reference frame. If an observer and an object like light move together in the same speed and direction, the speed of light according to the observer is 0. However, if the observer is at rest, then the speed of light is C. This is contrary to Maxwell's theory of electrodynamics stating that the speed of light is always equal to C in all reference frames.

Einstein's Magnet and Conductor

None of the physics textbooks mentioned TE of Einstein's magnet and conductor as shown in Table 4. Although most physics textbooks described two postulates of Einstein, there was no detailed explanation of how these postulates were obtained. Worse yet, there were physics textbooks that stated both Einstein's postulate based on the experiment of Michelson-Morley and had misrepresented Einstein's history of constructing the theory of relativity. In fact, both Einstein's postulates (the relativity postulate and the velocity postulate) were obtained through TE of Einstein's magnet and conductor as Einstein pointed out.

"…We will raise this conjecture (the purport of which will hereafter be called the "Principle of Relativity") to the status of a postulate, and also introduce another postulate, which is only apparently irreconcilable with the former, namely, that light is always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body. These two postulates suffice for the attainment of a simple and consistent theory of the electrodynamics of moving bodies based on Maxwell's theory for stationary bodies" (Einstein, 1920)

Einstein's Train

Only one of the physics textbooks presents TE of Einstein's train at the *satisfactory* level. In textbook C10, the authors showed the contradiction of Einstein's postulate then gave TE to support that contradictory. Here is an excerpt from TE' performance in physics textbook C10.

What if a train is moving with a speed of 0.6c and emitting a beam of light with a speed of c? According to the observer at rest in the station, the speed of light is 1,6c. This result is contrary to Einstein's light postulate that stated the speed of light remains c for all observers, does not depend on the state of motion of the observer or the source (Subagya, 2017)

Table 4 also shows 30% of physics textbooks present the idea of Einstein's train at the *poor* level. In this level, two physics textbooks only presented the result of Einstein's train without any background and performance. There was also a physics textbook that described the performance of Einstein's train by changing the content of TE, such as a train converted to an airplane.

Einstein's Twin Paradox

Only one of the physics textbooks presents TE of Einstein's twin paradox at the *satisfactory* level. In textbook C1, the authors described the background of Einstein's twin paradox as a result of time dilation, followed by the performance of twins, one wanders into space, and another settles on the earth. Over the years, they meet again but with different ages. The authors then described how to calculate their ages as the results of that TE. So, TE of Einstein's twin paradox becomes *satisfactory* because there were background, performance, and results.

In addition, there were two ways how the authors presented the Einstein's twin paradox. First, the authors presented it in the form of problem-solving. Obviously, there was no background and experimental result. So, TE becomes *poor* level. Second, Einstein's twin paradox was presented in the form of project assignment. Here, students reviewed some literature related to Einstein's twin paradox and presented it in the classroom. The following is an example of Einstein's twin paradox in the problem-solving form as shown in the textbook C7.

There are two twin babies, A and B. Baby A remains to be rest on the earth and baby B is taken away to the spacecraft at velocity 0.95 c. (a) If B is 20 years of old, how much old does A have? (b) If A is 20 years of old, how much old does B have? (Purwanto, 2009)

Based on the analysis of eight TEs in physics textbooks published and used in the Indonesian high schools today, it is clear that only a few physics textbooks introduced the idea of TEs as shown in Table 5. Only 20% of physics textbooks present Galileo's free fall and Galileo's relativity at the *satisfactory* level, and half of them did not mention Galileo's TEs.

For TE of Einstein's chasing a light beam, 90% physics textbooks did not mention it. Yet as it was mentioned earlier, this is the first TE by Einstein and became part of the special theory of relativity. TE of Einstein's train and Einstein's twin paradox are described only by one physics textbook at the *satisfactory* level. Similarly to Einstein's train, 60% physics textbooks did not mention Einstein's twin paradox. Sadly, three TEs (i.e., Newton's canon, Maxwell's demon, Einstein's magnet and conductor) were not mentioned in the Indonesian physics textbooks despite many opportunities to introduce them.

Table 5. The classification of TEs in the Indonesian physics textbooks

No	TEs	Classification			
		No Mention	Poor	Fair	Satisfactory
1	Galileo's free fall	4	2	2	2
2	Newton's canon	10	0	0	0
3	Maxwell's demon	10	0	0	0
4	Galileo's relativity	5	0	3	2
5	Einstein's chasing a light beam	9	1	0	0
6	Einstein's magnet and conductor	10	0	0	0
7	Einstein's train	6	3	0	1
8	Einstein's twin paradox	6	3	0	1

Table 5 also shows that there are nine TEs presented at the *poor* level and five at the *fair* level. In other words, 70% of TEs mentioned in Indonesian physics textbooks are at the *fair* and *poor* levels. In these levels, TEs cannot be used as tools to teach science knowledge due to lacking of background, performance, or results. These three elements are interrelated to each other in presenting the ideas of TEs. The presence of performance and results without a background will cause students not understand the history of TEs. Similarly, the presence of background and result without performance will cause students not know what TEs are. So, in general, TEs presented in the Indonesian physics textbooks cannot be used as an introduction in transferring scientific knowledge to science students.

Although several studies emphasized the importance of TEs in teaching and learning of physics (Lattery, 2001; Klassen, 2006; Velentzas & Halkia, 2013; Kosem & Ozdemir, 2013; Ince et al., 2016) most physics textbooks published and used in Indonesia did not present the ideas of TEs. Moreover, some physics textbooks are wrong in presenting the history of physics. For example, Einstein proposed his two postulates based on the results of the Michelson-Morley's experiment. This is not true because the two postulates of Einstein were based on the TE of Einstein's magnet and conductor. This is similar to study of Franklin (2016) that checked the historical accuracy of three experiments in physics (i.e., Robert Millikan's experiment, Michelson-Morley's experiment, and Ellis-Wooster's experiment). He found that many physics textbooks present an inaccurate history. Therefore a good teacher should be critical of what textbooks offer regarding learning and teaching of physics. Physics teachers are the decision-makers in choosing excellent textbooks for themselves as well as for their students. Teachers must have the ability in conducting learning evaluation (Yusrizal et al., 2017) and textbooks evaluation. For that reason, physics teachers must be really selective in choosing the textbooks as a guide in teaching the scientific knowledge to their students.

The absence of TEs in physics textbooks limits both teachers and students' to understand how scientific knowledge is built, developed, and maintained by scientists. Recently, Myhrehagen & Bungum (2016) reported the results from the project ReleQuant on how Norwegian physics students in upper secondary schools interpret the TEs. They argued that the lack of knowledge of TEs' history limited students' understanding of the physics concepts associated with it. Valentzas et al. (2007) also argued that students seemed to enjoy the story when learning the theory of relativity and quantum mechanics. The history of TEs presented attractively can spark students' interest in learning the concepts and principles of physics. Thus, it is necessary to teach TEs in historical perspective where there is a background, performance, and result of TEs.

TEs presented in historical perspective can be one of the most accurate tools in transferring scientific knowledge to students in the schools. It may help explain the physics concept more clearly and in detail. Further study is needed to design learning material that can accurately present TEs in physics. Collaboration between physics educators, historians, and philosophers of physics would be very useful both for making historical and epistemological roots of teaching TEs accurately and interestingly.

CONCLUSION

This study shows that physics textbooks published from 2009 to 2017 in Indonesia generally lack TEs. None of the physics textbooks mentions TEs of Newton's canon, Maxwell's demon, and Einstein's magnet and conductor despite the fact many opportunities could have introduced them. Only one physics textbook mentions TE of Einstein's chasing a light beam. Similar to TE of Einstein's train, Einstein's twin paradox was described by just one physics textbook at a *satisfactory* level. TE of Galileo's free fall and Galileo's relativity are described satisfactorily only by two physics textbooks.

The dissatisfaction of TEs in physics textbooks may be due to the fact that the authors have not realized the importance of TEs in the teaching and learning of physics. Many authors of the Indonesian physics textbooks ignored or inadequately presented TEs. Moreover, some of TEs were introduced in the form of problem-solving, essays, and even project assignments resulting in the loss of background and experimental results.

Finally, 70% of TEs mentioned in physics textbooks in Indonesia are at the *fair* and *poor* levels. So, in general, TEs presented in the Indonesian physics textbooks cannot be used as an introduction in transferring scientific knowledge to science students.

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