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INVESTIGATING THE PURPOSES OF THOUGHT EXPERIMENTS: BASED ON THE STUDENTS' PERFORMANCE

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ABSTRACT

The objective of this study is to examine the students' purposes in conducting thought experiments while solving physics problems. There were 12 pre- and in-service physics teachers as the participants in this study and divided into three groups with four students in each. Physics problem-solving activities were used as a context for observing students' processes in doing TEs. The results of the data analysis showed that there were three types of purposes of the students in doing the TEs during physics problem-solving activities: prediction, verification, and explanation. Therefore, it can be concluded that in the context of problem-solving, students design and run thought experiments as a creative ability tool to (1) predict solutions to the problem, (2) verify whether their hypothesis is correct or incorrect, (3) provide a detailed explanation to their hypothesis. Based on this study, we discuss the differences and similarities in the purposes of scientists and students in doing thought experiments. The importance and implications of thought experiments for current and future physics teachers are also discussed in the last part of this study.

Keywords: physics teacher; problem-solving; purpose; thought experiment

INTRODUCTION

Throughout the history of physics, thought experiments (TEs) plays an essential role in the development of physics theories. There are several examples where physicists used TEs to support their hypotheses or to criticize existing theories. For example, Albert Einstein introduced a TE from a train to support his hypothesis about time dilation (Einstein, 1905) or Erwin Schrödinger introduced a TE about a cat in a sealed box that may be simultaneously both alive and dead in order to refute Copenhagen's interpretation of quantum superposition (Schrödinger, 1935). Einstein's train, Einstein's twin paradox, Schrodinger's cat, Heisenberg's microscope, and EPR paradox are just a few examples of popular TEs used by physicists in developing modern physics, especially in the fields of relativity and quantum mechanics.

According to the most quoted definition, TEs are experiments in the mind laboratory that involve mental activities (Brown, 1991). TEs are a continuum of real experiments (REs) that are carried out in the mind's laboratory and be observed using the mind's eye (Galili, 2009; Buzzoni, 2013; 2019; Stuart, 2016) as opposed to the ideas that TEs is fiction (e.g., Elgin 2014; Meynell, 2014; Cameron, 2015). Marco Buzzoni, in a number of his effort, has been trying to convince us that TEs and REs are identical in principle and at least in physics; TEs are impossible without REs, and vice versa (e.g., Buzzoni, 2013; 2019). He argued that "(empirical) TEs without REs are empty; REs without TEs are blind" (Buzzoni, 2013, p. 100). TEs are thought and experimental activities (Galili, 2009; Bancong & Song, 2020b). Thought activities refer to modeling the imaginary worlds

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related to daily experiences of the experimenter and the scientific theories, while experiment activities refer to experimental activities in the laboratory, such as manipulating objects, variables, and making observations. Reiner & Burko (2003) and Brown (2006) suggested several similar steps of TEs: visualize imaginary worlds, perform experiments, and describe the results. These three activities as the steps of conducting TEs performed by individuals.

Since TEs have a central role in the history of science and philosophy (Machery, 2011; Asikainen & Hirvonen, 2014; Arfini et al., 2019), some researchers are interested in studying the role of TEs in education, especially physics education. For instance, Velentzas & Halkia (2011) implemented a TE of Heisenberg's Microscope as an instructional tool for teaching uncertainty principles to upper secondary education students. They also implemented the TE of Einstein's elevator and Einstein's train for teaching the theory of relativity (Velentzas & Halkia, 2013). The results showed that the utilization of TEs could enable students to recognize the situations which refer to a world outside of their daily. The use of TEs can also reveal students' hidden reasoning when working on complex physics problems (Kösem & Özdemir, 2014) and can deepen their understanding of physics concepts (Klassen, 2006; Galili, 2009). Several physics researchers have carefully investigated the use of TEs in high school physics textbooks (e.g., Bancong & Song, 2018). Recently, Bancong & Song (2020a) has identified the factors that influence students' in constructing TEs: students' bodily knowledge, students' imaginary visual knowledge, opposing ideas, similar ideas, and support from group mates. These five factors encourage students to do TEs when they are solving physics problems collaboratively. In short, several studies have shown that TEs have an essential role not only for developing physics theories but also for teaching and learning of physics.

However, some questions related to the use of TEs for students in schools have not been clearly answered. For example, if physicists generally use TEs as a creative ability device to support and refute the existing theories or to produce new theories (Brown, 1991; Galili, 2009; Thagard, 2014; Fehige & Stuart, 2014), do students use TEs with the same goals as scientists? If not, then what is the function of this imagination tool for students as a representation of non-experts?. Previous studies have not provided a clear description of students' goals in doing TEs. Meanwhile, understanding the process and purposes of students in conducting TEs is significantly beneficial in a way that it can provide us with complete and more precise information of how students conduct TEs, as well as generate ideas about what needs to be done in helping students to develop and enhance their TEs experiences.

Therefore, the objective of this study is to examine the purposes of students in doing TEs. In our previous study (Bancong & Song, 2020b), we had explored the processes of TEs carried out by students when they were working collaboratively to solve physics problems provided. The findings revealed that given the context of collaborative problem-solving activities, students could design, discuss, share opinions, rethink, and review their TEs, which signifies that the TEs can be established and directed together even though they initially appear in personalized versions. Furthermore, the study also showed that in the process of evaluating the results of TEs, students employed four sources of evaluation, namely conceptual understanding, past-daily experience, logical reasoning, and conceptual-logical inference (Bancong & Song, 2020b). This study, therefore, is a follow up to the previous one. In this study, we present physics problems for small groups of students. While solving the problem, we carefully observe the processes of students doing TEs and investigating their purposes. So, the research question in this study was, "what are the students' purposes in conducting TEs while solving physics problems?"

METHODS

As mentioned earlier, this study's objective was to examine the students' aims in doing TEs while being involved in solving physics problems. Therefore, the qualitative approach was considered the best methodology to achieve the objective. Merriam & Tisdell (2016) stated that qualitative research is all about creating an understanding of how people make sense out of their lives, depict the process (rather than the outcome or product) of meaning-making, and describe how people interpret what they have experienced. Likewise, Miles et al. (2014) stated that in qualitative research, researchers took data about participants' perceptions through a process of deep attention and empathic understanding.

Participants

Considering the purpose of the study, we selected 12 pre- and in-service physics teachers as participants. Pre-service physics teachers are prospective physics teachers who are pursuing teacher education. They are the 7th-semester students at Universitas Muhammadiyah Makassar. Instead, in-service physics teachers are students who have obtained a bachelor's degree in physics education and have taught physics at school, and for now, they are pursuing master education to improve and develop their knowledge and skills continuously. These participants were then divided into three groups, with four students in each group. Adhering to the principles of research ethics, we used only the initials of the participants' names to protect their identity. Additional information regarding the participants in each group can be seen in Table 1.

Table 1. Information about Participants

Group	Members	Gender	Status
1	AN	Female	In-service teacher
	AF	Female	In-service teacher
	AE	Female	In-service teacher
	FA	Female	In-service teacher
2	MY	Male	In-service teacher
	AA	Male	In-service teacher
	SS	Female	Pre-service teacher
	DS	Female	Pre-service teacher
3	NN	Female	Pre-service teacher
	RR	Female	Pre-service teacher
	NI	Female	Pre-service teacher
	MH	Male	Pre-service teacher

Instrument and Procedures

Several studies have mentioned that both scientists and students used TEs as an imagination tool when they are solving problems (Clement, 2009; Kösem & Özdemir, 2014). Therefore, we used physics problem-solving activities to see how students deal with the problems by using TEs. Those physics problems were adapted from a book entitled *Thinking Physics Is Gedanken Physics,* written by Epstein (1995). The term "Gedanken-experimente" was used in the book as a synonym for TE. This book provides a set of problems in physics, which was designed to activate students' imaginary world so that it allows them to conduct TEs while solving these problems. We picked up some potential problems from that book for discussing. After that, we conducted a pilot study with several students to evaluate whether the potential problems can make students carry out TEs while solving those problems. Based on the results, we selected the five most potential physics problems that stimulated and triggered the students to carry out TEs as instruments in this study.

In order to collect data, first of all, we organized students into groups and presented the physics problems. We also provided each group with blank sheets of paper that they could use to write or to draw whatever comes up in their mind during the physics problem-solving process. In these activities, we carefully observed students' processes in solving these problems and identified the TEs that occurred. All of these activities were recorded using two cameras, from the front and behind the participants. Because each group had to work on five problems, we conducted observation and recording five times for each group.

Furthermore, students' notes and the researcher's notes were used as additional data resources to ensure the validity of the data. The students' notes were those written and drawn freely by the participants while doing the TEs or discussing with the other participants. Meanwhile, observation notes collected by the researcher were outlines about the steps or procedures of TEs the students conducted during problem-solving activities. These two kinds of notes helped to justify TEs processes described in audio and video recordings transcripts. To sum up, there are three methods of collecting data used in this research, namely audio and video recorded during the process of discussion, students' notes, and the researcher's observation notes. The following Figure 1 shows a diagram of the data collection processes.

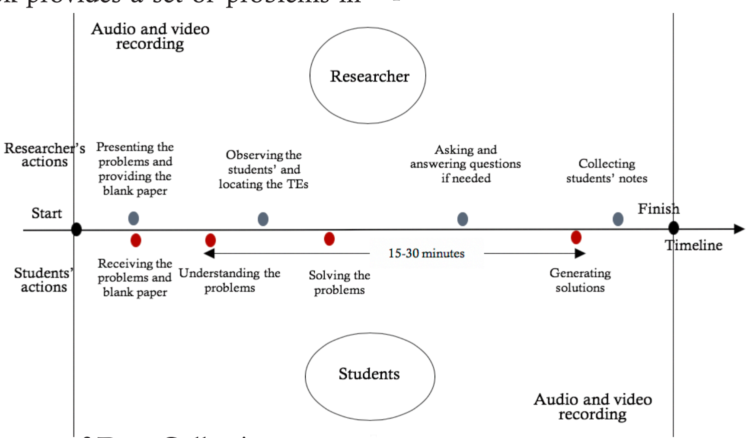


Figure 1. The Process of Data Collection

Merriam & Tisdell (2016) suggest that researchers act as participant-observers in collecting qualitative data. By using this method, the researchers have sufficient space to access many people and detailed information. However, we realized that the involvement of the researcher might create effects on the process.

Therefore, to reduce the possibility of interactive discourse occurred between the researcher and the participants in this study, we minimized the intervention. In this case, the researcher engaged in dialogue only when needed, as the students were sometimes confused about what to do. The forms of interventions that the researcher carried out were asking participants if the problem given was clear or unclear, responding to participants' questions related to the problem, asking them what they thought about something to clarify their thinking, and asking them about what they can conclude after solving the problem given.

Data Analysis

As the primary data sources were the audio and video recordings of each group, transcribing activity was the first step done in the data analysis process. In this step, not a single utterance in the conversations carried out by participants during the physics problem-solving activities was missed. For the next step, we reviewed the audio and video recordings in order to obtain a more in-depth insight of the TEs that appeared after identifying the TEs features in the transcripts of episodes of physics problem-solving activities. When we recognized a discourse that looked like a TE, we paid more attention to the episode in the video. Third, the discourse that has been identified as TEs in the second step was then confirmed by using the researcher's observational notes and students' notes. These two kinds of notes helped to determine and highlight the TEs parts in the data transcripts. We then watched and listened to the video repeatedly to make sure that there are no TEs episodes that are missed from the second step.

Reiner & Burko (2003) and Brown (2006), as referred earlier, suggested three procedures of TEs generally performed by individuals while solving physics problems, namely 1) illustrating imaginary worlds, 2) conducting experiments, and 3) explaining the results. After determining the TEs episodes in the transcript, we went further to analyze the students' objectives in conducting TEs. To conduct the analysis, Miles et al. (2014) proposed coding activity as the first step to summarize parts of the data in the raw transcriptions. The codes resulted in the first cycle coding process were then clustered under some specific categories. We read the transcripts repeatedly to ensure that we found all intentions conveyed by the students either implicitly or explicitly. Finally, through the deductive method, the three main categories of students' goal for doing TEs when solving physics problems were grouped into prediction, verification, and explanation.

Miles et al. (2014) suggested peer review as a technique of checking the reliability of the analysis. Therefore, we invited two physics education researchers to identify the processes and purposes of students conducting TEs. The two researchers separately analyzed 75% of the total transcripts of the audio and video recordings that were obtained. We examined and organized the results of the analysis until about 92% agreement is reached. We also discussed the results with the participants to check whether there was any misinterpretation of the data. Besides, we also received positive responses from academics when presenting the findings of this study at an international conference.

RESULTS AND DISCUSSION

The results of the data analysis showed that predicting, verifying, and explaining are three main reasons for students doing TEs while working on physics problems. When the students utilized a TE to deal with the challenge they are working on, the motivation behind students' TE goals is coded as "prediction." Conversely, when students utilized a TE to check whether their assumption or hypothesis is correct or incorrect, at that point, the reason for students' TE is coded as "verification." Lastly, when students utilized a TE to give further clarifications about their assumption or hypothesis, at that point, the motivation behind students' TE goals is coded as "explanation".

Table 2 below presents the distribution of the students' purposes in doing TEs while solving physics problems. As we can see, 4 of the 8 TEs carried out by group 1 were used to provide further explanation for their hypothesis. The others are used to predict the answers to the given questions and to prove their hypotheses. When the researcher finished reading the problem, group 1, whose members were all in-service physics teachers, tended to propose hypotheses or assumptions first as answers to the problems they faced. Their hypothesis was based on their prior knowledge or experience. They then designed and conducted TEs to be used as a creative ability device to provide detailed explanations of their hypothesis.

Table 2. Distribution of the Students' Purposes in Conducting TEs

Purposes of TEs	Participant/Problem (P)														
	Group 1					Group 2					Group 3				
	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5
Prediction		**									*	**	**	*	*
Verification		*			*	*	**					*			
Explanation	*		*	*	*			*	**	*					*

Furthermore, 4 of the 7 TEs generated by group 2 during physics problem-solving activities were also used to provide further explanation of their hypothesis. The rest of the TEs generated by group 2 were used to prove their hypothesis as the temporary answers to the problems they faced. Group 2 members were a combination of in-service and pre-service physics teachers.

Conversely, 7 out of 9 TEs generated by Group 3 are instead used to predict the solution to the problems they face. There was only 1 TE generated by group 3, which aims to verify their hypothesis and another one to provide a more detailed explanation of their hypothesis. The members of group 3 were all pre-service physics teachers. When the researcher has read out the problem, group 3 members generally did not have an assumption or a hypothesis as a temporary answer to the problem. Thus, group 3 tends to directly visualize the imaginary world and then design a TE when they solved the problem. The results of their TE was then used as a solution to the problem they faced. The further explanation of these three purposes of TEs is presented in the sections below.

Prediction

The results of data analysis showed some evidence that students used TEs as a creative ability tool in guessing the answers to the questions given. In this case, when students were faced with physics problems, they did not immediately propose hypotheses or assumptions as temporary answers to the problems. Instead, students first used their imagination, designed a TE, and described the results. Hadzigeorgiou (2016) stated that although one can imagine without being creative, one cannot be creative without being imaginative. Students then used the results of the TE as solutions to the problem given. The words, such as "I think the situation is like this," "that it is," or "aha," are typical words that were often said by students when they were designing and running TE to predict solutions to the problems they face. The following is an example in which the student utilized a TE to presume an answer to the problem. The transcripts presented below is a piece of the transcript of problem-solving activities from group 3 while solving the second problem. The problem presented an illustration of two scientists sitting in different boxes. The students were required to think and determine which scientist in can recognize her motion in the space: the scientist who is in the straight-moving box or the one in the smoothly-turning box, as illustrated in Figure 2.

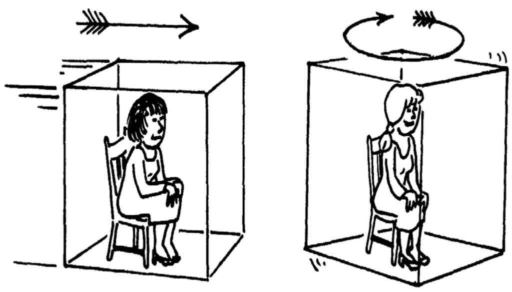


Figure 2. Scientists in the Box as an Illustration of Problem 2. Adapted from *Thinking physics is Gedanken Physics* (p. 104), by L. C. Epstein, 1995, insight press

R: *We move to Problem 2 [the researcher then reads the question]. So, what do you think about this problem? Which scientist can detect her motion?* 1

[. . .]

MH: *Aha, I think the situation is like this. [1]Imagine if we are inside a ship that is straight-moving at a constant speed. But, because we cannot see outside, we do not know whether we are moving or not. [2]If I drop something, a pen, or whatever in the ship. Let us say gravity exists there, [3]then the thing I drop will fall straight down, not left behind.* 2

NI: *Yeah, we will not realize that we are moving.* 3

NN: *Yes, it is similar to this [the situation in the Problem]* 4

MH: *So, for me, the woman who feels that she is not moving is the one in the straight-moving box. How about you guys?* 5

R= Researcher; 1 = visualize imaginary world; 2 = perform experiment; 3 = describe the results

As we can see in line 2, MH was doing a TE to find out the answer to the given problem. MH immediately imagined an imaginary world by saying, "I think the situation was like this" when the researcher finished reading the problem (Line 1). At this moment, MH did not have a hypothesis or a prior assumption as a solution to the question given. MH suddenly visualized an imaginary world, and then designed and run experiments in his mind and achieves the results. The words "imagine if" were highlighted as a sign of visualization, which indicates that MH was starting to visualize an imaginary world. As expected, MH visualized an imaginary world by imagining himself inside a ship that moves straight ahead. Because MH could not see outside, he did not know whether he was moving or not. In this situation, MH then experimented by dropping several pens on a ship that was moving at a constant speed. MH saw the pen that was dropped would still fall perpendicularly by using his mind's eye, just like when the ship was still not moving. MH then used the result of this TE as a solution to the problem given. MH then concluded that the scientist in the straight-moving box would not feel that she is moving. The case described above shows that the students make use of the TEs as a tool of imagination to figure out the solution to the problem as stated by Sorensen (2016), TEs as a tool of the imagination for investigating the nature of science.

Verification

The results of data analysis also show that students used TEs as a creative ability device to verify their hypotheses that have been proposed earlier as a temporary answer to a given problem. The students constructed a hypothesis based on their daily experiences or scientific theories. As the researcher completed the reading of the problem, some students put forward assumptions or hypotheses first as a solution to the problem they are facing. They then conducted TEs to verify whether their assumptions or hypotheses were correct or incorrect. The words, such as "right?" "maybe?" "Won't we?" or " isn't it " are typical words that were often said by participants when they were designing and running TEs to verify their hypotheses or assumptions. The transcript presented below when group 2 was working on problem 1 is an example of this case. Problem 1 was asking whether there is the effect of rain on the trolley's speed, as illustrated in Figure 3.

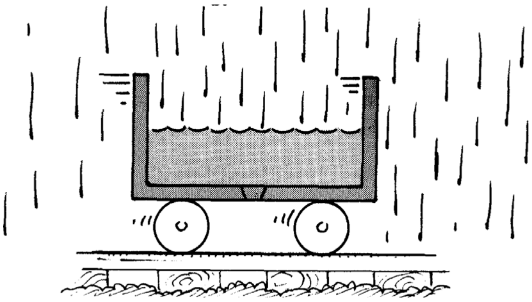


Figure 3. Trolley in the Rain as an Illustration of Problem 1. Adapted from *Thinking physics is Gedanken Physics* (p. 87), by L. C. Epstein, 1995, insight press

AA	*Well, in my opinion, there is the effect of rainwater on the trolley.*	2
SS	*Really? For me, not. The speed of the trolley will remain constant.*	3
MY	*So, is there no effect of rainwater on the trolley's speed?*	4
SS	*Yes, I think so. Right [while looking at AA]?*	5
AA	*No. In my view, the speed of the trolley will get affected. [1]Imagine if we played with a toy car. Imagine If the toy car is launched on an inclined plane. [2]If I push this trolley, consider a toy car [pointing to the trolley's image on the problem given], [3]then it will slide, right? Now, [1]imagine if [2]we filled this toy car with stones, for example. [3]Its speed is faster than those that are not filled, right? So, a toy car that is filled with stones will slide faster than those that are not filled.*	6
	[. .]	
MY	*For me, I think like that. Suppose the toy car that is pushed by [AA] would slide faster if the mass is greater on the inclined plane. It is the same as this [indicating the trolley], the trolley will slow down . . . At a specific time, it will stop because its mass increases continuously.*	7
AA	*Yes, it will stop over time.*	8
MY	*Right, I agree with you [AA] . . . Like this [while pointing the trolley's images on the problem given]. This trolley will be filled with rainwater continuously. So, over time, this [indicating the trolley] will get heavier, so, the speed will slow down and continue to slow down. . .*	9

As we can see in the transcript, AA did a TE (Line 6) to prove his hypothesis that the speed of the trolley will be affected (Lines 2 and 6). At the beginning of the discourse, all participants actively participated in understanding the problem. When MY asked AA, AA said that there is an effect of rainwater on the trolley's speed (Line 2). SS suddenly responded and rejected AA's assumption. According to SS, the trolley's speed will always remain constant in the heavy rain (Line 3). It means that there is no effect of rainwater on the trolley's speed. However, AA rejected SS's opinion and hypothesized that the rainwater would affect to the trolley's speed. To prove his hypothesis, AA then experimented with his mind.

The words "imagine if" uttered by AA (line 6) were indicators of visualization. It indicated that AA was starting to visualize an imaginary world. As we can see in the transcript above, AA experimented with his mind by launching the toy cars. First, AA visualizes an imaginary world by imagining himself launching toy cars that were filled with stones and without stones on an inclined plane. By using his mind's eye, AA then observed the speed of these two toy cars. AA noted that a toy car filled with stones would slide faster than those without stones. This TE proved that its mass influences the velocity of an object. Similar to the trolley that moves in heavy rain. The speed of the trolley will slow down and continue to slow down until it may stop because its mass increases continuously. After conducting a TE, AA then invited the rest of the team to rethink and review the opinion together to achieve mutual understanding. The example described above shows that students use TEs as an imaging tool to verify their hypothesis.

Explanation

Lastly, the results of the data analysis showed that some students designed and conducted TEs to be used as a creative ability device in providing further explanations for their hypotheses. For this purpose, students did not directly designed and run TEs when they are facing a problem but instead proposed hypotheses first. They constructed hypotheses based on scientific theories or their daily experiences. After constructing hypotheses as to the temporary answer to the problem, they then run TEs to be used to support their hypothesis. The words, such as "to illustrate," "for instance," and "for example," are typical words that were often said by students when they were designing and running TEs for this purpose. The transcript presented below when group 2 was working on problem 3 is an example in which the students used TE to provide more explanation for their hypothesis. Problem 3 asked about a horizontal plane, which of the path representations is closest to the trajectory of the after coming out of point 2, as illustrated in Figure 4.

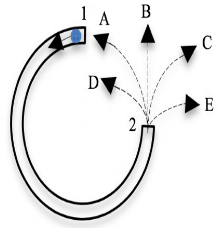
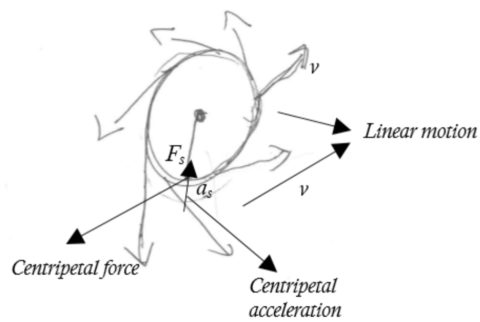


Figure 4. Ball in the Semicircular Channel as an Illustration of Problem 3

R	*. . . So, which is the path of the ball after exiting at point 2?*	*1*
MY	*I think it is B.*	*2*
DS	*Yes, B.*	*3*
R	*Why?*	*4*
MY	*Because of the vector of velocity. [1]if, try to imagine, for example, [2]the ball is suspended and is rotating above [while demonstrating it with his hand] [3]then is suddenly released. The ball is pointing out, like B. That is what is in my mind, what about you?*	*5*
	[. . .]	
MY	*Yes, the direction of the velocity is always like that. Its direction is always perpendicular to radial acceleration. Like this*	*6*



[This picture shows a circular path of the objects in the trajectory written by MY while working on problem 3]

After listening carefully to the problem read by the researcher (Line 1), MY suddenly hypothesized that the solution to the problem given was B, as shown in the transcript above. DS also supported MY's assumption by saying, "yes, B." These two participants proposed answers to the issue provided without any attempt to do TE first. When the researcher asked, why did you choose B ?, MY answered that it is the direction of the velocity vector (Lines 2-5). This hypothesis proposing by MY was based on his prior knowledge when studying physics. MY then did a TE by first saying the word "for example" to provide further explanation of his hypothesis.

As we can see, MY visualized the imaginary world by using the words "if" and "try to imagine." He then experimented with his mind and showed with his left-hand spinning above. In his experiment, MY tied a ball with a rope then rotated it on the top. By using his mind's eyes, MY saw that when the ball was released, then the ball would come out perpendicularly, like point B, on the given problem. To support the results of the TE, MY then evaluated it using the concept of circular motion (Line 6). MY believed that the ball would come out perpendicularly based on the velocity vector concept that he has learned before. In the physics concept, the acceleration vector always points to the circle center, while the velocity vector points to the direction of motion. Thus, this example shows that students perform TEs as an imaging tool to be used to provide more explanation for their hypothesis.

The findings of this study support the previous studies that both scientists and students used TEs as a cognitive tool when they are solving physics problems (e.g., Clement, 2009; Kösem & Özdemir, 2014). All participants in this study—regardless of their status—were able to design and run experiments in their minds. There are some moments in this study where the students carried out more than one TEs for one physics problem, as shown in Table 2. This may indicate that TE is a natural process that occurs suddenly as a reaction to the problem.

The study has shown that while working on physics problems, the participants utilized TEs as a creative ability tool to guess the solution to the given problem, to verify their assumption or hypothesis, and to give detailed explanations to their assumption or hypothesis. In prediction, when participants were faced with physics problems, they first constructed an imaginary world and then designed and run experiments. The results of experiments conducted by participants in their minds were then used as solutions to the problems. In verification, when students were faced with physics problems, they first proposed a hypothesis or an assumption as a solution to the problem. Students' hypothesis is based on their daily experiences or scientific theories. The students then designed and run TEs to verify whether their hypothesis or assumption was correct or incorrect. In explanation, students also proposed a hypothesis first, and then designed and run a TE to provide further explanation of their hypothesis. Figure 5 below illustrated the students' purposes in conducting TEs while working on physics problems.

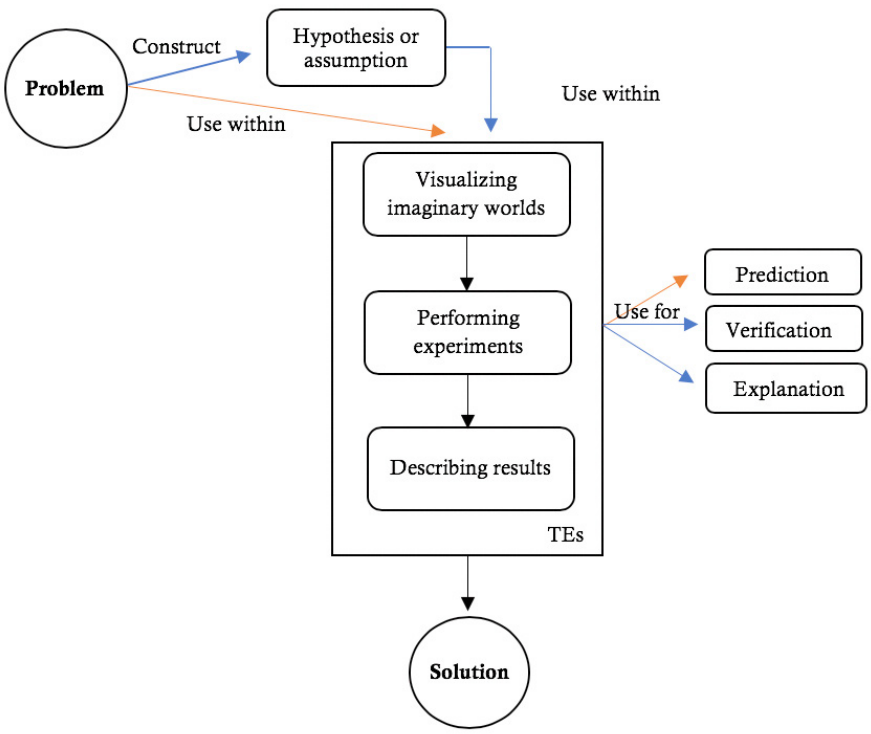


Figure 5. Illustration of the Students' Purposes in Conducting TEs while Solving Physics Problem

Although both physicists and students utilized TEs when solving complex issues, they showed different basis of performing TEs. Students simply design and run TEs intuitively without any plans or prior intention. The processes of the students' TEs was undoubtedly not in the same way as what the prominent scientists had been doing, such as Schrodinger's cat, which is used by Erwin Schrodinger to disapprove the Copenhagen's interpretation of quantum mechanics (Schrödinger, 1935) or Einstein's magnet and conductor to refute Maxwell's view of ether theory and simultaneously produced the relativity theory (Einstein, 1905). The TEs conducted by the students are less complex in which they are applied mainly to comprehend the situation in the proposed problem. Moreover, the TEs generated by students are mostly validated based on their experience. It is in contrast to the TEs produced by scientists that are based on robust scientific theories.

The result of this study also shows that both scientists and students use TEs to support their hypotheses further. Students used TEs to verify whether their hypothesis is correct or incorrect or to provide further explanation about their hypothesis. Similarly, scientists also used TEs as cognitive tools in developing and supporting their hypotheses and theories (Galili, 2009; Thagard, 2014; Fehige & Stuart, 2014). Also, both scientists and students used TEs as an argumentation tool. The contradictory opinions among the students in the discussion may bring a positive impact as it can stimulate them to explore different views. In the end, this situation is expected to be able to increase the students' motivation to carry out a TE in order to find support for their ideas and, at the same time, reject their opponent's ideas. Likewise, in some cases, physicists also used TEs to counter opposing ideas and simultaneously generate new ideas. TE of Galileo's free-falling body and Einstein's magnet and conductor are examples of this case. This kind of TE is termed as platonic TE (Brown, 1991).

CONCLUSION

This study concluded that in the context of problem-solving, students use TEs as a creative ability device for three purposes: prediction, verification, and explanation. This study has shown that students not only design and conduct TEs to predict the solutions to the problems they are facing but also to confirm and prove whether their hypothesis is correct or incorrect. Some students used TEs as a creative ability device to provide a detailed explanation of their hypothesis as a temporary answer to the problem at hand.

Based on the results of this study, we would recommend introducing TEs to physics teachers and prospective physics teachers as it can be a useful creative ability tool for teaching physics at schools. Physics materials, such as thermodynamics, quantum, and relativity theories, have great potential to introduce and integrate TEs in teaching physics at schools. We also thought for the authors of school physics textbooks would introduce and present TEs in detail. Physics textbooks play an important role in introducing TEs due to the tendency of today's physics teachers to teach physics based on textbooks. Overall, TE is an essential part of the history and philosophy of physics and, therefore, an essential inclusion in the physics teaching process in schools.

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