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High school physics teachers' perceptions and attitudes towards thought experiments in Indonesia

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Abstract
Thought experiments have a crucial role in the discovery of physics theories. Yet, in order to properly use thought experiments in the classroom, teachers must have enough pedagogical knowledge and abilities. This study aims to explore the perceptions and attitudes of high school physics teachers toward thought experiments. In this study, we involved 30 physics teachers from different schools in both urban and rural schools. The data were collected through questionnaires and semi-structured interviews. The quantitative and qualitative analysis results demonstrate that physics teachers have a high awareness of the importance of thought experiments in physics learning, especially atomic theory and relativity, and perceive themselves to lack skills regarding the pedagogical aspects of thought experiments. Teachers also show positive attitudes and beliefs about teaching thought experiments. However, teachers still recognized the challenges of implementing thought experiments in the classroom. The teacher suggests that thought experiments be carried out collaboratively so that students can share ideas with each other. Furthermore, technology media such as virtual reality may be the ideal

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answer for assisting students in visualizing an imaginary environment when doing thought experiments in the classroom.

Keywords: attitude, perception, physics teacher, thought experiments

1. Introduction

Throughout the history of physics, there have been two kinds of experiments used by physicists to examine a hypothesis: real experiments (REs) and thought experiments (TEs) (Stuart *et al* 2017, Bancong and Song 2020a). REs are experiments conducted in real laboratories by using real tools and materials (Dohrn 2016, Egan 2016). In contrast, TEs are experiments done in our minds by involving mental manipulations (Bancong and Song 2020a, Stuart 2021). TEs have both thought and experimentation as constituent parts (Buzzoni 2019, Bancong and Song 2020a). The thought element entails modeling an imagined world connected to theory and experience, whereas the experimental element relates to hands-on activities in real life, such as changing variables and objects during experiments. TEs have been undeniably playing a crucial part in the development of science. As widely recognized by the physicists community, Galileo used the TE of falling bodies to refute the gravitational theory of Aristotle, Newton used the TE of cannonball to support his hypothesis that the force of gravity was universal, and Einstein used the TE of magnets and conductors to explain the concept of relative motion and introduced two important postulates in the development of the relativity theory. They are well-known scientists who use TEs in their work and are part of the journey to invent their great works. In the world of physics, physicists use TEs to develop scientific knowledge, formulate new concepts, and represent their views on a topic (Bancong and Song 2018, Alstein *et al* 2021).

Although there is still very little information about the cognitive mechanism that supports learning from TEs, several literatures have provided ways in which students can advance their knowledge through TEs activities. Several physics researchers have revealed the pedagogical implications of TEs and stated that TEs are useful in promoting conceptual understanding (Fleer 2019, Alstein *et al* 2021), fostering the understanding of the history and philosophy of science (Velentzas and Halkia 2013, Balukovic *et al* 2017, Stuart 2021) and increasing motivation, confidence, and attitudes towards physical theories (Asikainen and Hirvonen 2014, Myhrehagen and Bungum 2016). TEs can effectively help students to interpret their social and moral realities more adequately by giving them opportunities to explore the scope of standardized concepts (Fleer 2019, Balg 2022). This can, in some cases, even help reduce hermeneutic injustices that already exist (Balg 2022). Furthermore, by using TEs in physics class, students are stimulated to use their imagination and prior knowledge to solve the problems presented by (Kösem and Özdemir 2014, Cameron 2015, Kamphorst *et al* 2021). TEs can be used to activate intuition as a basis for learning that is relevant to scientific theories (Bascandziev 2022). TEs can also help students identify the characteristics of a phenomenon based on their previous experiences in their daily activities (Hadzigeorgiou 2016, Irikefe 2022). In addition, TEs can help students to develop creative thinking skills and encourage students to exchange ideas during discussions (Bancong and Song 2020a). The results of the study using TEs supported by event diagrams to present a relativistic world also show success in supporting students to develop a conceptual understanding of relativistic theory (Kamphorst *et al* 2021).

In the context of Indonesia, there has been relatively little study on TEs. Bancong and Song (2018), for example, have evaluated 30 physics textbooks commonly used by teachers and high school students in Indonesia and discovered that 70% of the TEs offered in high school physics textbooks in Indonesia are at the level of fair and poor. At this level, the TEs still need to be fully presented, starting from what it is, how the TES is done, and what the results are like. Nurjanah *et al* (2019) designed computer-based e-learning teaching materials that emphasize using TEs to improve student conceptual understanding. They claim that the teaching materials that have been designed are valid and reliable based on the judgment of media practitioners and content experts. de Raedt *et al* (2012) also said that theories of quantum physics could be well understood using TEs. Bancong and Song (2020b) have also investigated whether factors encourage and discourage students from engaging in TEs. They argue that both internal and external factors can lead to TEs. Students' internal factors are connected to their own knowledge (both conceptual and experiential), while external factors are related to their interactions with others in the classroom (conflicting ideas, similar ideas, and support from experienced students).

Despite the consensus on the importance of TEs in physics learning, there is still little understanding of the process that physics teachers go through in designing learning, especially their perceptions and attitudes toward TEs. Previous studies reveal more about the processes, difficulties, and benefits experienced by students in learning by involving TEs (Asikainen and Hirvonen 2014, Myhrehagen and Bungum 2016, Balukovic *et al* 2017, Fleer 2019, Alstein *et al* 2021, Balg 2022). In fact, there are still very few studies that further investigate the implementation and implications of TEs in the teaching of physics at schools, particularly those related to the physics teachers' understanding, beliefs, or practice of TEs in teaching physics. Studying teacher views and attitudes will add to the international literature by adding on what is presently known (Ramnarain and Fortus 2013, Harada *et al* 2022).

This work will contribute to the international literature by expanding what is currently known about how teachers perceive TEs in different educational contexts. The findings of this study will also help to establish TEs-based research as a topic of study in the Indonesian context and will have implications for physics teachers, especially in Indonesia and in countries with similar educational contexts, on how to effectively prepare physics teachers to use TEs in physics teaching at school. Therefore, this study aims to determine the perceptions and attitudes of high school physics teachers in Indonesia regarding the TEs. The research questions framing this study were:

a. How do physics teachers view TEs in teaching physics in schools?
b. What is the physics teacher's attitude towards teaching TEs in schools?

2. Method

This study employs a mixed methods approach. A mixed methods study, according to Creswell and Creswell (2018), is research that combines the collection of quantitative and qualitative data and then integrates the two types of data to solve research problems.

Combining quantitative and qualitative methods in one study gives more comprehensive and objective research results than using only one of them, such as a quantitative or qualitative approach (Creswell and Creswell 2018).

The design used in this study is an explanatory sequential mixed methods design. In this design, researchers conduct quantitative research first, followed by qualitative research to provide a detailed explanation of the results (Creswell and Creswell 2018). Therefore, in this study, we collected and analyzed quantitative data using a questionnaire first and then qualitative data using interviews to further explain the first-stage results.

This study involved 30 physics teachers from three different areas: urban, suburban, and rural areas in South Sulawesi, Indonesia. Each region contributed ten participants with 3–10 years of experience in teaching physics at schools. We utilized a code for all participants as recommended by standards for conducting ethical studies.

The data were collected by using a questionnaire for quantitative data. The development of the questionnaire was carried out in three stages: the first stage involved determining the questionnaire scale and developing the items, the second stage involved performing an initial review and revision, and the third stage involved determining the validity and reliability of the questionnaire items. The questionnaire that was employed comprised of 20 statements that were connected to the teachers' perceptions and attitudes concerning

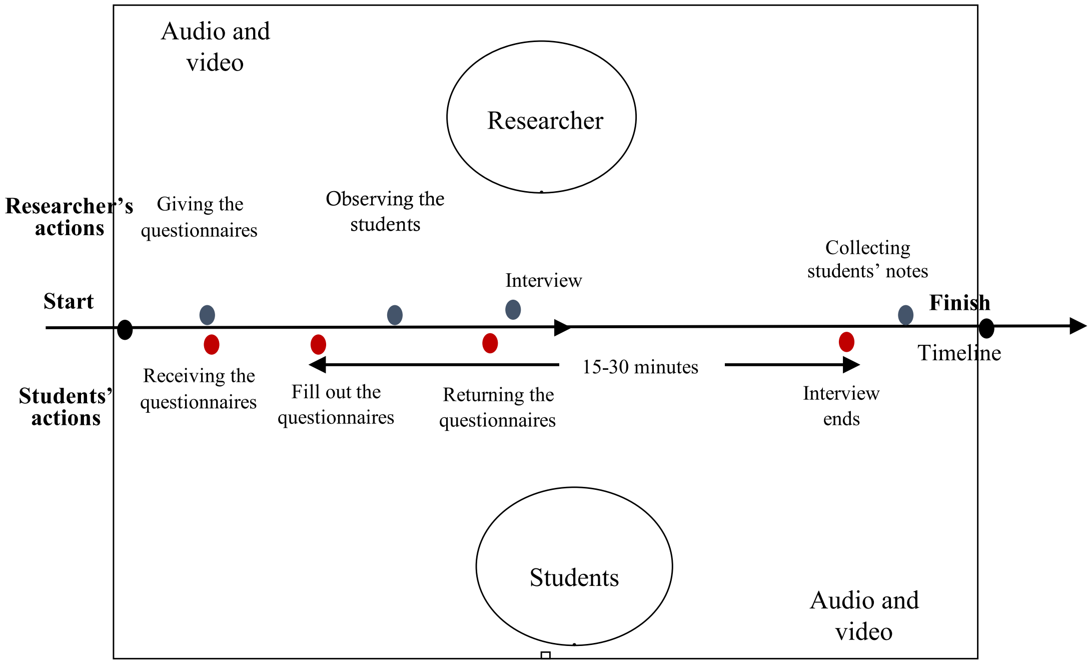

Figure 1. The procedure of data collection.

TEs. This questionnaire had been validated by two experts before it was used. The questionnaire utilized a Likert scale with four points, with highly agree receiving four points, agree receiving three points, disagree receiving two points, and strongly disagree receiving zero points.

In addition, we used semi-structured interviews to gather qualitative data. The interview questions were developed to supplement the data obtained from the questionnaire and to acquire a full account of the perceptions and attitudes that teachers have toward the instruction of TEs. Every single interview was both transcribed and recorded audibly. Figure 1 illustrates the several steps involved in the data-gathering process.

Data from the questionnaire were then analyzed to describe teachers' perceptions and attitudes toward TEs. SPSS software was used to determine the distribution of teachers' responses and the mean and standard deviation of each questionnaire item. Furthermore, the interview data was coded in two distinct phases for analysis (Saldana 2015). Initial transcriptions were coded in a first cycle to summarize data. Then, we looked for patterns within the codes generated by the initial cycle coding and clustered them into similar categories. As we reached a point in our investigation when no new information could be gleaned, we shifted our attention to gathering more data to back up the previously established categories. Analysis integrity was ensured by double-checking all contributing members (Miles *et al* 2018). The findings of this research have also been presented at an international conference, where they were met with generally favorable reactions from academics in attendance. One way to boost the credibility of research is by having it subjected to the scrutiny of other researchers, which can take the form of conversations with one's colleagues or presentations at a conference (Creswell and Creswell 2018).

3. Results

The results of this study are divided into four sub-section: the perceptions of physics teachers about the core aspects of TEs-based instruction, the challenges of TEs-based instruction, the pedagogical knowledge needed for TEs-based instruction, and attitudes and beliefs about TEs-based instruction. Each section presents quantitative data obtained from the questionnaire results

Table 1. Physics teachers' perceptions of the core aspects of TEs-based instruction.

No	Statements	SA	A	D	StD	M	SD
1	I think the thought experiments require teachers to use appropriate instructional strategies.	18	10	2	0	3.53	0.63
2	I think the thought experiments require students to use various learning resources.	15	13	2	0	3.43	0.63
3	I believe that thought experiments require students who can think critically.	18	12	0	0	3.60	0.50
4	I believe that thought experiments require students who can think creatively.	19	9	2	0	3.57	0.63
5	I think the thought experiments require the teachers to be well-versed in physics content.	23	6	1	0	3.73	0.52

SA: strongly agree; A: agree; D: disagree; StD: strongly disagree; M: mean; SD: standard deviation.

and is followed up by qualitative data obtained from interviews. In the end, a discussion is presented that describes the results obtained with the basic concepts and previous studies.

3.1. Perceptions of the core aspects of TEs-based instruction

This scale depicts the physics teachers' perspective on the main aspects of TEs-based instructions in teaching physics. We used five items that intended to describe the physics teachers' perspective on the learning design and resources, as well as teacher attributes as shown in table 1. The result of the questionnaire revealed that most of the physics teachers tended to strongly agree that in implementing TEs in physics classrooms, they need to select appropriate instructional strategies ($M = 3.53$) and prepare adequate learning resources to be used while teaching through TEs ($M = 3.43$). Teachers are also supposed to plan activities that promote students' critical analysis ($M = 3.60$) and argumentative skills (3.57), which are very useful in doing TEs. In addition, most of the physics teachers admit that teachers must master the physics content that are being discussed when implementing TEs in the classroom.

Recognizing the necessity, the teachers acknowledged some alternatives that could be applied in the classroom while implementing TEs in teaching physics. The following interview excerpts reflect the teachers' ideas:

> I often use TEs when teaching the theory of relativity, and my students love it… Teachers can use methods such as **collaborative learning in teaching TEs**. This will keep students enthusiastic so they can debate and share ideas with each other. (Teacher AA)
>
> From what I have seen, some schools either do not have enough teaching facilities or do not provide an internet connection to their students. Preparing **student worksheets** with information or data about TEs from multiple sources will be very useful. (Teacher AB)
>
> ***Videos*** *can be a great way to introduce high school students to scientific discovery or physics concepts. There are several videos illustrating how TEs work, and I use them when teaching physics… If they are going to grasp this issue (how TEs work), they need to see a demonstration or be* ***demonstrated using meaningful illustrations****. (Teacher AJ)*

The interview results revealed that most teachers believed that teaching TEs through collaborative activities would help students stay motivated in learning. Collaborative activities are

Table 2. Physics teachers' perceptions of the challenges of TEs-based instruction.

No	Statements	SA	A	D	StD	M	SD
6	I think physics teachers may struggle to incorporate thought experiments into their lessons.	17	12	1	0	3.53	0.57
7	I think physics teachers may struggle to find suitable teaching materials to implement thought experiments.	20	8	2	0	3.60	0.62
8	I think physics teachers may struggle to organize students' learning activities to implement thought experiments.	18	11	1	0	3.57	0.57
9	I think physics teachers may struggle to integrate thought experiments with the national physics curriculum standards.	12	17	1	0	3.37	0.56
10	I think physics teachers may struggle to identify appropriate physics topics to implement thought experiments.	15	12	2	1	3.37	0.76
11	I think physics teachers may struggle to link physics subject with thought experiments appropriately in the same lesson.	15	13	2	0	3.47	0.63

SA: strongly agree; A: agree; D: disagree; StD: strongly disagree; M: mean; SD: standard deviation.

designed to engage the students into learning and sharing with their friends (Bancong and Song 2020a). Learning physics together may advantage the students in a meaningful way that students can express and confirm their opinions or even debate to defend what they have conveyed; they can also receive new input by considering their friends' ideas. In addition, teachers also consider the technological tools that can facilitate learning through TEs. Yet, some schools in Indonesia, especially in rural areas, are still lacking of facilities and access to the Internet (Syamsuri and Bancong 2022). Therefore, to deal with those technology limitations in schools, teachers may need to provide worksheets for students. Worksheets offer information and description on the topics provided as well as helpful exercises to promote students' critical thinking in doing TEs. On the contrary, in schools where the Internet is provided or can be accessed easily, videos can be great media to explain the science theories that are, in the end, expected to stimulate the students to create better visualization in mind while solving problems through TEs.

3.2. Perceptions of the challenges of TEs-based instruction

The second scale described the difficulties experienced by physics teachers in integrating TEs in their classrooms. There were 6 items given, and all were presented in negative statements, as shown in table 2. Items 6 and 8 deal with the teachers' challenges in adjusting their teaching style and designing activities during the implementation of TEs. Item 7 and 10 focuses on how teachers selected teaching materials and topics when teaching through TEs, while item 9 and 11 the challenge in linking the components of TEs the curriculum applied and how to integrate physics lesson into TEs.

The data shows that, in general, most of the teachers believed that they probably would find obstacles when implementing TEs in teaching physics. Designing teaching materials that are suitable for running TEs seemed to be the biggest problem for the teachers ($M = 3.60$). Many teachers are still very dependent on textbooks, yet, many physics textbooks do not provide adequate sources for doing TEs (Bancong and Song 2018).

Teachers would need to put extra effort into finding and select materials that can be used in solving problems through TEs. Moreover, the challenge are getting higher when the schools are located in rural areas where teachers cannot the Internet access is not available. The following excerpt shows what the teacher assumes about this:

> *It seems to me that it is difficult for a physics teacher* ***to access relevant teaching materials*** *for implementing thought experiments. This may be new (thought experiment) for some teachers, especially teachers in rural schools. We only use books that are available as is (Teacher AE)*

Another concern of the teachers was how to integrate TEs in physics topics. Teachers are required to acknowledge what topics that are suitable to be used in TEs. The teachers are aware that TEs can only be used to explain certain physics theories and topics; some physics lessons are better be delivered using REs. Therefore, they should decide what they are before starting to design the lesson and activities in the classroom.

> *There are also common challenges encountered when teaching physics…* ***Not all physics topics can be taught using a thought experiment approach****. For example, in the topic of electricity, ohm's law… students understand more easily if they use direct experiments in the laboratory (Teacher AJ)*

Furthermore, teachers also assume that the students may find it challenging to imagine things and make them 'work' on their minds. Proper teaching aids will help them to better visualize the world through TEs. Teachers mentioned a sophisticated media such as virtual reality as one of the innovative tools to teach TEs.

> *Yes, I always use TEs when teaching physics that requires it, such as the TE of Galileo's free fall when teaching the theory of motion or Einstein's twin paradox when teaching the theory of time dilation. However,* ***The most difficult challenge in my opinion is to visualize an imaginary world when doing thought experiments****. Therefore, we need technological media such as virtual reality to help students visualize an imaginary world (Teacher AL)*

3.3. Perceptions of the pedagogical knowledge required for TEs-based instruction

As indicated in table 3, the third scale of this questionnaire tries to determine teachers' perspectives on the pedagogical knowledge required for TEs-based instruction. The four items developed (items 12–15) were supposed to examine teachers' knowledge on how they design learning, including their understanding in formulating TEs to develop students' arguments, understanding the content knowledge of the topic presented, understanding in adjusting the components of the National Curriculum standard with TEs, and understanding in designing learning activities during the implementation of TEs.

The data shows that at least a half of the participants tended to disagree with the four items; they admitted they have less knowledge related to the TEs integration and design in the teaching and learning in physics class. Interestingly, the teachers' biggest concern for most of the teachers seemed to be their understanding in physics concepts or principles that should be developed when teaching through TEs. Besides, they were also confused about how to engage the students with appropriate activities so that they could run TEs properly. The following interview excerpts support the questionnaire data:

> ***It is difficult for me to use this strategy*** *[TEs] because it is unfamiliar to me …* ***The most difficult aspect for me is figuring out how to engage students to conduct thought experiments.*** *(Teacher AT)*
>
> ***I am not convinced I can control the classroom atmosphere in***

Table 3. Physics teachers' perceptions of the pedagogical knowledge required for TEs-based instruction.

No	Statements	SA	A	D	StD	M	SD
12	I am able to develop pedagogical goals for physics thought experiments that encourage students' reasoning.	5	8	15	2	2.53	0.86
13	I know the physics content knowledge (physics facts, concepts, and principles) necessary for implementing thought experiments.	2	8	15	5	2.23	0.82
14	I am able to integrate thought experiments into the National physics curriculum standards.	8	7	13	2	2.70	0.95
15	I know the kind of activities that students must engage in when learning physics through thought experiments.	7	8	12	3	2.63	0.96

SA: strongly agree; A: agree; D: disagree; StD: strongly disagree; M: mean; SD: standard deviation.

> ***such a way that students are actively involved****. My biggest issue is how to handle the different classroom activities associated with teaching thought experiments and asking the types of questions that can encourage students to perform thought experiments (Teacher AW)*
>
> ***Designing physics lessons with a thought experiment approach requires extra effort****… As a new teacher with only 3 years of teaching experience,* ***I guess I still lack the capacity*** *to choose problems and prepare lesson plans and teaching materials. (Teacher AO)*

In the interview, the teachers conveyed that they doubted their competence in managing the classrooms and developing needed materials. Many of the teachers are not really familiar with TEs, so they assume that it would be hard to immerse themselves and the students into a new learning approach that requires students to work with their imagination and not the real situations as what they usually do in real laboratories. They might have to be out of their comfort zone and sacrifice extra effort if they wish to fully use TEs in their teaching. Moreover, the teachers are also not confident whether they can develop appropriate materials to facilitate learning in the students' minds, which is unseen. The materials chosen and presented to students should be able to raise their curiosity so that they are motivated to conduct the TEs under the teachers' instruction.

3.4. Attitudes and beliefs about TEs-based instruction

The last part of the questionnaire highlighted the teachers' attitudes and beliefs regarding the use of TEs-based instruction in physics classrooms. There were five items revealing teachers' willingness to use TEs as a part of their teaching (item 16), willingness to collaborate with colleagues to develop TEs teaching materials (item 17), and willingness to maximize the use of TEs in teaching by attending professional development programs (item 18), and their beliefs in the effect of TEs in their teaching (item 19 and 20). Table 4 shows the physics teachers' attitudes and beliefs about TEs-based instruction.

The questionnaire analysis results suggest that the majority of the teachers are willing to start using and developing TEs in their classrooms to help the students understand physics concepts. Using TEs gives students the opportunity to feed their own curiosity so they can build their creativity in solving problems. Yet, the teachers are aware that they still need reinforcement to improve their ability to implement TEs, and they are very open to programs that can advance their knowledge and the practice of TEs in physics classrooms. The most interesting data is that all of

Table 4. Physics teachers' attitudes and beliefs about TEs-based instruction.

No	Statements	SA	A	D	StD	M	SD
16	I am eager to incorporate thought experiments into my physics teaching.	15	14	1	0	3.47	0.57
17	I am eager to work with other physics teachers to create thought experiment teaching materials.	14	13	3	0	3.37	0.67
18	I am eager to participate in professional development programs that support teachers in implementing thought experiments.	12	17	1	0	3.37	0.56
19	I feel that thought experiments will assist students in meeting the national physics curriculum standards.	10	14	5	1	3.07	0.78
20	I think thought experiments are a good way to teach physics and help students learn how to argue scientifically.	20	10	0	0	3.67	0.48

SA: strongly agree; A: agree; D: disagree; StD: strongly disagree; M: mean; SD: standard deviation.

the teachers are quite sure that TEs are a great way to develop students' critical and creative thinking as they comment and try to find solutions to problems presented. They express their opinions and even debate to defend what they think is right; this will help them develop their reasoning skills. The following excerpts further explain the teachers' attitudes and beliefs toward the implementation of TEs in physics lessons.

> ***I am interested in the thought experiment approach*** *and will try to facilitate my students with this approach. (Teacher AS)*
>
> ***I plan on incorporating thought experiments into my lessons****…. I believe that engaging in thought experiments can increase* ***students' interest*** *in physics and help them develop their* ***ability to think creatively.*** *(Teacher AC)*
>
> Forcing students to argue with one another, as in [**collaborative thought experiments**], might help them develop **critical thinking skills** and enhance **their argumentation**. (Teacher AL)

4. Discussion

The first scale of the data describes the teachers' perception on the core aspects of TEs. The participating teachers acknowledged that there are several things they should consider when implementing TEs in teaching physics. The teaching strategies and design of activities in the classroom are among the teachers' concerns in implementing TEs in the classroom. The majority of teachers agree that the selection of appropriate teaching strategies, sources, media, and activities for students will determine the success of implementing TEs in teaching physics. Moreover, TEs are activities done in mind, so the teachers really need to make sure the 'invisible work' runs well in each student's head. Related to this, the teachers first suggested collaborative learning activities to make learning more optimal. Doing work together creates the opportunity for students to open conversations, discussions, and even debates that are expected to lead to various new perspectives. Scientific discussion and argumentation are essential in doing TEs. Not only serve as a great means in learning, scientific discussion is also an important basis in developing scientific knowledge (Erduran *et al* 2006, Chowning 2022). In addition, teachers also can take the chance to improve students' argumentation skills by encouraging students to explore diverse ideas during the discussion (Parmin *et al* 2022, Tang 2022), and in the end, students will advance their thinking skills, communication skills, and their understanding about the nature of science (Songsil *et al* 2019).

Furthermore, the teachers also commented about the learning media for students to maximize the implementation of TEs. They mentioned students' worksheets as a tool to deliver the concept of science being learned and to prepare exercises related to the concepts, particularly when Internet facilities are not available at schools. (Hernita and Djamas 2019) claimed that the use of students' worksheets enables the optimization of students' understanding of concepts as they provide various activities or discussion materials for students. Another teaching tool that is likely to be chosen by most teachers is video. The teachers believed that by using videos, the students are easier to comprehend the lesson. Videos, if used properly, can help stimulate ideas about the physics topic being discussed and develop students' interest in the lesson as it provides real visualization of the application of physics (Kettle 2020).

The second scale of the data seeks what difficulties the physics teachers might encounter in integrating TEs into teaching and learning process. The data shows that the teachers are highly aware of the challenges in many aspects of TEs implementation. They believed that extra efforts are needed in changing the teaching style, preparing materials, adjusting TEs aspects into the physics curriculum applied, designing classroom activities, and choosing the right topic for doing TEs. However, among all, the biggest worry lies on how to select learning resources to facilitate learning through TEs-based instruction. They implied that textbooks are just not enough. They will need additional learning materials and more advanced media to make learning through TEs more optimal. In fact, plenty of great materials can only be accessed via the Internet, whereas many schools in Indonesia cannot provide Internet access for teachers and students at schools due to either isolated locations or inadequate budgets (Syamsuri and Bancong 2022). The infrastructure in some schools in rural areas is still very insufficient and needs improvement to support learning. In addition, teachers also wished a more sophisticated media, such as virtual reality to run TEs even better. Virtual reality makes it possible for the users to interact with that environment as in real life, which in turn facilitates learning by doing (Durukan *et al* 2020).

Most of the participating teachers also focused on the difficulty in selecting the right topics to be delivered through TEs. In physics, there are various topics to be taught, but not every topic can be explained using TEs-based instruction. Some topics. Therefore, it becomes an obstacle for teachers to classify which topics are suitable to go along with TEs and which ones are better learned through REs. One of the topics that can be specifically explained via TEs is special relativity theory (Alstein *et al* 2021). They reported that TEs help students to understand the conceptual features of special relativity theory.

The third scale reveals about the pedagogical knowledge the teacher should possess to implement TEs-based instruction and how teachers perceive themselves regarding their capacity. The questionnaire results analysis shows that the majority of the teachers admitted they still lack of knowledge needed in applying TEs-based instruction in teaching physics. For some teachers, TEs-based instruction is a new approach, so they need more time to entirely comprehend it and adjust it to their teaching. Moreover, the experiments are done in mind; no one can see them. Hence, the teachers, who facilitate learning in class, may need to find ways to engage students in those abstract processes. The teachers should ensure that what the students do is a scientific thinking process, not an illusion or merely a thought exercise (Bancong and Song 2020a).

Also, the teachers felt less confident in designing the lesson plan for TEs. The lesson plan is a crucial part in designing learning. In making a plan for a specific lesson, particularly when using TEs, teachers must be competent enough to select materials and problems to be solved through TEs, what learning media to be used, and what kind of assessment should be used. Unlike integrating the concept into the REs that most teachers are already familiar with, linking the concept into TEs might need extra effort for the teachers. Teachers must be able to explain the TEs in detail in lesson plans so that they can be well-organized.

The fourth scale intends to describe the teachers' attitudes and beliefs about TEs-based instruction. The result of the analysis shows the teachers' positive views on the implementation of TEs in physics classrooms. Teachers are simply their willingness to integrate TEs in their teaching as they are highly sure that TEs will be advantageous to students' learning. They are also ready to grab opportunities to improve their competencies through any professional development programs.

In the interview, the teachers shared their optimism about the implementation of TEs and the benefits the students may gain from them. As they implied earlier, TEs are something new for the participating teachers and most probably for the students as well. The teachers assumed that TEs would attract students' attention and build their curiosity as they are accustomed to REs only in most physics lessons. In addition, despite the fact that TEs are abstract thinking, the teachers believed that the process of finding solutions to certain physics problems through TEs might improve the student's creativity and scientific argumentations.

5. Conclusions

Based on the data analysis, it can be concluded that most physics teachers understand that it is crucial to implement TEs in physics learning for their obvious benefits on the students' thinking process and concept comprehension. The teachers also show positive attitudes and beliefs about involving TEs in the teaching process. Therefore, TEs must be given special attention in the Indonesian National Physics Curriculum. Despite the fact that a number of physics teachers have used TEs to teach physics in their classrooms, the use of TEs as a strategy for learning physics has not been explicitly included in the Indonesian National Curriculum.

Furthermore, teachers also understand that they need to enhance their skills on the pedagogical aspects of TEs in order to support the application of TEs during learning. They recommend that TEs be carried out collaboratively so that students can share ideas with each other and improve their critical thinking. In addition, as an effort to familiarize the use of TEs in physics lessons, we need technology media such as virtual reality in order to support the students' visualization when doing TEs in the classroom. Thus, the findings of this study can be used by policymakers as a consideration for the further development and incorporation of TEs into the Indonesian national Physics curriculum. The absence of TEs in teaching physics, such as the special theory of relativity or free fall, will limit students' ability to understand how physicists construct, develop, and maintain scientific knowledge.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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Ethical statement

This research was approved and carried out in accordance with the principles outlined by the research ethics committee at the Universitas Muhammadiyah Makassar. All teachers that participated in this study gave their informed consent to participate, including permission for the results to be published.

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