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Investigation of Student Difficulties in Physics Learning and Readiness to Implement Physics Learning Using Bifocal Modeling-Based Practicum in Indonesia

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Abstract

A research has been carried out to obtain the overviews of difficulties faced by students in learning physics and readiness to implement physics learning using bifocal modeling-based practicum. It was done in a senior high school in Bandung, Indonesia. The research subjects were two physics teachers and seventy nine students enrolled in the academic year of 2020/2021. This research was a qualitative case study, in which the data was collected through questionnaires, observations, and interviews. The questionnaires were used to reveal students' responses to physics learning and potential implementation of physics learning using bifocal modeling-based practicum. Observations were used to get overviews of physics learning process and school infrastructures. Interviews were used to reveal barriers faced by teacher in organizing physics learning and reveal difficulties faced by students in understanding physics concepts. Based on the data analysis, it was found that: 1) students are difficult to understand theoretical and mathematical physics concepts, 2) teachers face barriers to organize a physics learning due to several factors, i.e. limitation of time, abundance of curriculum teacher tasks, limitation of supporting facilities, 3) the infrastructures of the school are good enough to support the implementation of physics learning using bifocal modeling-based practicum.

Keywords: student difficulties, physics learning, bifocal modeling-based practicum

Introduction

The rapid global changes in information and communication technology (ICT), has affected the availability of technology and made it pervasive. The use of technology in society has triggered changes in employment and education. The new skills needed for navigating education and the workplace in the current century have labeled 21st skills (Siddiq et al., 2017). The 21st century is known as knowledge age characterized by the openness and globalization. It means that the efforts of meeting demands of life in society are based on the information-driven and globally networked knowledge (Triling & Fadel, 2009; Wijaya et al., 2016).

There are four groups of skills that should be acquired by students through the 21st century learning, i.e. ways of thinking skills, ways of working skills, tools for working skills, and skills for living (Wilson et al., 2015). Ways of thinking skills consist of creativity and innovation, critical thinking, problem solving, decision making, learning to learn and metacognition. Ways of working skills consist of communication and collaboration. Tools for working skills consist of information literacy and ICT/ digital literacy. Meanwhile, skills for living consist of methods on how students can live as a citizen who have careers and both personal and social responsibilities as well as cultural awareness (Wilson et al., 2015). There is widespread consensus, however, that our education systems are failing to adequately prepare students with the essential 21st century knowledge and skills necessary to succeed in life, career, and citizenship (Kay, 2010).

Physics as a part of education system plays an important role in participating to prepare students so they have a set of 21st century skills. In the relation to the 21st century learning, Indonesian government mandates the process of learning should be organized by applying scientific and knowledge-based approach, in which teachers facilitate students to do a set of activities consisting of observing, questioning, experimenting, associating, and communicating (BSNP, 2010). Hence, by doing those activities, students are able to get meaningful scientific experiences, conduct what scientists do, and understand the essence of science (physics), i.e. physics is scientific product (body of knowledge), physics is scientific process (ways of investigating), and physics is scientific attitude (ways of thinking) (Sutrisno, 2006).

One of physics learning methods which can be used to give students with meaningful scientific experiences is practicum method. Physics practicum aims to demonstrate basic principles of physics and introduce students to laboratory instruments, kits, and tools, so students can use them for a given purpose and develops practical skills (Gupta, 2013). By doing physics learning through practicum, students are able to understand the essence of science (physics) and acquire knowledge, experiences, practical skills, and higher order thinking skills needed to face life in the 21st century. Practicum activities enable students to have motivation in learning and improve learning achievement. They also become the means used by students to perform scientific methods (Hofstein & Lunetta, 2004).

Although practicum or laboratory work has benefits for students as aforementioned above, its implementation has not been optimal. It is caused by some factors, such as the limitation of laboratory instruments, kits, and tools; physics laboratory room functioned as a classroom; the absence of laboratory assistant or technician affecting the time taken to organize practicum activities (Katili et al., 2013). Poor condition of laboratory instruments, kits, and tools also is identified to become another factor (Putri et al., 2014). Moreover, the problem of practicum implementation in senior high school level become more severe for theoretical, mathematical, and abstract concepts. For this kind of concepts, students have no opportunities to observe physics phenomena that deal with what they learn in the form of those theoretical, mathematical, and abstract concepts, so concept understanding and creative thinking skills of students are relatively low (Hermansyah et al., 2015). One of theoretical, mathematical, and abstract concepts in physics is kinetic theory of gases. This concept is often taught by lecture method, students are then given physics problems that are mathematical. Physics understanding of senior high school students due to theory kinetic of gases in a given district in Indonesia was relatively low, ranged from 12 % to 59 % (Agustina et al., 2018).

Nowadays, however, there is a rapid development of computational science and engineering (CSE) technology which can be utilized as a tool for overcoming the aforementioned problems of physics practicum implementation. The CSE technology can be integrated into a learning method for facilitating students with project-based scientific activities and visualizing theoretical, mathematical, and abstract concepts, so it can improve the quality of learning (Vieira et al., 2018). The technology is also possible to design a learning, in which students can observe microscopic abstract phenomena, interact with a computer model, find a scientific model, compare the experimental and the computerized data, and at the end students can develop a critical perspective of scientific models. This kind learning design can be organized in a learning by using bifocal modeling-based practicum method. It applies advanced technologies, consisting of CSE technology and sensors. The implementation of bifocal modeling framework in science learning has been proven to significantly improve both content and metamodeling knowledge of student. Schwartz defined metamodeling knowledge as a knowledge about modeling enabling students to answer questions about how and why scientific models are used, as well as the strengths and limitations of such models (Fuhrmann et al., 2018).

Bifocal modeling framework in physics learning offers potential solution to several problems of physics practicum. Hence, the adoption of bifocal modeling framework into physics learning should be thoroughly studied. Some focuses of study that may be done for getting overviews as the basis of bifocal modeling practicum development are difficulties faced by students in learning physics which can be potentially overcome by implementing bifocal modeling practicum and the readiness to implement physics learning using bifocal modeling-based practicum, in terms of supporting infrastructures and the readiness of teachers and students. This study was conducted to reveal them.

Methodology

This research is a qualitative case study. Case study is the first type of research that can be utilized in the field of qualitative methodology. It offers at least four advantages in comparison to quantitative methods, i.e. case study can be potentially used to achieve high potential validity, has strong procedures for fostering new hypotheses, is useful to examine the hypothesized role of causal mechanisms in the context of individual cases, and has capacity for addressing causal complexity in a specific context (Starman, 2013). This research was carried out in a senior high school in Bandung, Indonesia. The research subjects were two physics teachers and all students enrolled in grades 10, 11, and 12 at the school in academic year of 2020/2021.

The data in this research was collected by questionnaires, used for revealing the students' responses to physics learning and potential implementation of physics learning using bifocal modeling-based practicum; observation, used for getting overviews of physics learning process and school infrastructures; and interviews, used for revealing the barriers faced by teacher in organizing physics learning and revealing difficulties faced by students in understanding physics concepts. The data collected was then compared to documents owned by teachers which correlate with physics learning activities. The documents consist of syllabus and lesson plans, physics textbooks, worksheets, test instruments, test scores. The data was then sorted, simplified, and categorized. Quantitative data obtained from questionnaires was analyzed quantitatively. Meanwhile, the data obtained from interviews, observations, and documentation is analyzed descriptively and qualitatively.

Results

This research succeeded in revealing some findings, classified into five main parts, i.e. 1) findings dealing with the students' responses to physics learning, 2) findings dealing with the students' responses to the potential implementation of physics learning using bifocal modeling-based practicum, 3) findings dealing with the overviews of physics learning process and school infrastructures; 4) findings dealing with the barriers faced by teachers in organizing physics learning; 5) findings dealing with difficulties faced by students in understanding physics concepts. These findings are described below, but it will be preceded by a short description of the framework of bifocal modeling-based practicum.

1. *Bifocal modeling framework*

Bifocal modeling framework (BMF) is an inquiry-driven science learning approach which links student's physical experimentation with computer modeling in real time. The BMF challenges students to design, compare, and examine the relationships between physical experiments and computer or theoretical models. As part of BMF activities, students explore natural phenomena such as heat diffusion, the properties of gases, and bacterial growth through physical experimentation, the design of computer models, and the comparison of the measured and simulated data gathered from these distinct empirical and virtual modalities (Fuhrmann et al., 2018). Bifocal modeling approach involves students in investigating a natural phenomenon through synchronization of a real experiment and a digital computerized model. It requires students to design, compare, and test the data gathered from a real experiment and the data generated from computerized model (Blikstein, 2014).

Bifocal modeling learning is different from a learning by using a computerized model or simulation. It is because in the bifocal modeling learning, students have an opportunity involve in designing both the real experiment and computerized experiment. Moreover, in the bifocal modeling learning, students are able to "revise" a scientific model based on the results of their observation and comparison between the data gathered from the real experiment and the data generated from the computerized experiment. In a bifocal modeling practicum, students design and do a real physics experiment connected with a sensor system to a virtual model. Students then compared the data generated from the real experiment and the data from the virtual model (Fuhrmann et al., 2018). Generally, the bifocal modeling framework is shown in Figure 1.

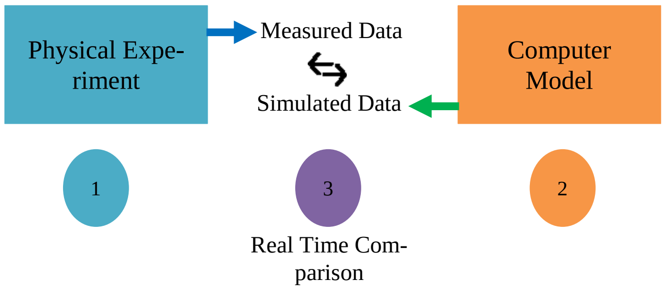

Figure 1. Bifocal modeling framework

2. *Students' responses to physics concepts*

Students' responses to physics learning were obtained by using questionnaire consisting 10 questions. Students participated in filling out the questionnaire were seventy nine and the results are shown in Table 1.

Table 1. The results of questionnaire dealing with the students' responses to physics learning

No.	Statements	Responses (%)	
		Agree	Disagree
1.	I am very excited to learn physics.	5	94.94
2.	I like to learn physics when teachers teach me using various learning methods.	100	0
3.	Practicum (laboratory work) is one of learning methods I like the most.	87.34	12.66

No.	Statements	Responses (%)	
		Agree	Disagree
4.	I like to learn physics when teachers teach me using various learning media.	100	0
5.	I can understand all physics concepts I have learnt in classroom.	2.53	97.47
6.	I can understand all physics concepts, the phenomena of which are easy to find in everyday life.	84.81	15.19
7.	I like learning physics when teachers show me the applications of the physics concepts.	88.61	11.39
8.	I like learning physics when teachers show me both the real and simulated phenomena of the physics concepts.	89.87	10.13
9.	I get difficulties in understanding theoretical, mathematical, and abstract physics concepts.	97.47	2.53
10.	The use of information of communication technology in physics learning may improve the physics concept understanding of students.	97.47	2.53

3 Students' responses to the potential implementation of physics learning using bifocal modeling-based practicum

Students' responses to the potential implementation of physics learning using bifocal modeling-based practicum were obtained by using questionnaire consisting 18 questions. In this research, before doing this questionnaire, students were given short information due to the bifocal modeling practicum, so they got general overviews about such type of practicum. Students participated in filling out the questionnaire were seventy nine and the results are shown in Table 2.

4 Overviews of physics learning process and school infrastructures

The overviews of physics learning process and school infrastructures were obtained through observations. The first observation was carried out in a physics classroom, focused on the methods and models used by teachers in organizing learning which were matched with the lesson plans made by the teachers. Based on the classroom observation, it was revealed that teachers mostly used lecture method, in which students were involved in questioning and answering activities due to physics concepts presented in the textbooks. After that, students were served by some physics problems to be solved. Moreover, the learning process did not apply a certain specific learning model. However, based on the analysis to lesson plans made by the teachers, the learning process should implement a given learning method other than lecture method and also should apply a certain model of learning.

Meanwhile, the second observation was focused on the school infrastructure which may support the implementation of bifocal modeling practicum. One of the key infrastructures that should be present in a school for implementing bifocal modeling-based physics practicum is infrastructure that deals with information and communication technology. In this case, the findings of observation dealing with infrastructures are 1) the observed school has a physics laboratory which is also functioned as chemistry and biology laboratories, 2) laboratory equipment found in that school consists of 4 kinds of kits (magnet and electricity, heat and thermodynamics, optics, and mechanics, 3) there is a proportional computer laboratory consisting of 25 PCs connected by local area network (LAN), and 4) there is internet network which are well accessible from all classrooms, 5) all students (about 20 per class) have android mobile phones.

Table 2. The results of questionnaire dealing with the students' responses to the potential implementation of physics learning using bifocal modeling-based practicum

No.	Statements	Responses (%)	
		Agree	Disagree
1.	Practicum is important in physics learning.	100	0
2.	Physics practicum helps students to better understand physics concepts.	100	0
3.	Physics practicum helps students to develop measuring skills.	92.41	7.59
4.	Physics practicum helps students to bring up the curiosity to a certain natural phenomenon.	84.81	15.19
5.	Physics practicum helps students to develop the ability of prediction.	88.61	11.39
6.	Physics practicum helps students to develop critical thinking skills.	91.14	8.86
7.	Physics practicum helps students to develop creative thinking skills.	89.87	10.13
8.	Physics practicum helps students to develop problem solving skills.	89.87	10.13
9.	Physics practicum helps students to develop communication skills to present physics facts, concepts, and principles.	100	0
10.	Physics practicum can improve the motivation of students in learning physics.	100	0
11.	Physics practicum is always done in physics learning at school.	0	100
12.	There is physics laboratory in my school.	100	0
13.	Information and communication technology can be used as physics practicum tools.	100	0
14.	I can't find real phenomena dealing with theoretical, abstract, and mathematical physics concepts in daily life.	100	0
15.	Theoretical, abstract, and mathematical physics concepts should be taught using visualized virtual practicum.	100	0
16.	I can be more motivated to learn physics when I know the exact meaning of the physics concepts.	92.60	3.8
17.	Computer visualization helps me to understand a certain physics concepts.	100	0
18.	Combining real experiment with simulated (virtual) experiment can make me obtain holistic understanding of a given physics concept.	97.47	2.53

5 Barriers faced by teachers in organizing physics learning

The overviews of barriers faced by teachers in organizing physics learning were obtained through interviews to two physics teachers. The results are summarized in Table 3.

Table 3. Summary of interviews with teachers

Questions	Summarized Answers	
	Teacher 1	Teacher 2
Do you plan lessons in various ways based on the characteristics of physics concepts?	Yes, I planned lessons based on the characteristics of physics concepts. I planned a set of methods and a given learning model. However, in	Yes, I planned lessons based on the characteristics of physics concepts. The lesson plans were made to-

Questions	Summarized Answers	
	Teacher 1	Teacher 2
How do you implement your lesson plans?	its implementation, sometimes it is not matched with the plan because of some factors, such as the limitation of time, abundance of curriculum tasks, limitation of supporting facilities.	gether by all physics teachers. We planned some learning methods and models that should be performed in every lesson meeting. Sometimes, teachers modify the lesson plans depending on the condition, at which the lesson plans are being implemented.
Could you describe your activities in general in a physics learning?	I usually starts my learning activities with preparing a lesson plan, textbook, test instrument. After that, I implement teaching that is sometimes based on the lesson plan and sometimes is not.	I usually start my lesson with discussion, give students a certain physics problem to be discussed in a classroom, give students extra physics problems and homework.
How is the enthusiasm of your students in your class?	My students are very enthusiastic when I teach physics concepts that are relatively not complicated and minimum mathematic formula. They are also enthusiastic when I show videos and animations or other interesting media.	Overall, my students are enthusiastic in doing physics classroom activities, especially when I demonstrate a certain phenomenon, perform physics practicum, and discuss the application of physics in daily life.
Have your teaching methods enabled students easily understanding physics concepts? Could you explain your answers?	Mostly, not yet. It is because students mostly face difficulties in applying the concepts in solving physics problems.	Not yet. Low formative scores of physics compared to those of other courses indicate the students' physics concept understanding is not good enough.
What do you think about the needs of students to have a sets of 21^{st} century skills? Could you explain your answers?	I think students should have all 21^{st} century skills needed to adapt in the 21^{st} century life.	I think 21^{st} century skills are vital for students. It is because these skills determine the ability of students to survive in this century. Students do not only need knowledge, but they also need such skills.
What methods have you implemented to enable students of having 21^{st} century skills?	I facilitate students with various activities that bring them closer to the 21^{st} century skills, such as giving homework which requires students to explore and utilize digital resources.	I sometimes give students examples of implementation of physics in advanced technologies.
Do you teach all physics concepts base on the curriculum in	No, the limitation of time become the problem.	It depends on the availability of time that sometimes clashes with other curriculum tasks.

Questions	Summarized Answers	
	Teacher 1	Teacher 2
one academic year? Could you explain your answers?		
What do you think about the implementation of practicum method in your school? Is practicum needed in physics learning? Could you explain your answers?	Practicum is very essential for physics learning. It can make students apply scientific methods.	Practicum should be implemented in physics learning. Through practicum students are motivated to learn physics concepts. Students also apply scientific works. Practicum enables students to feel what scientists do.
How often do you open your classes by implementing practicum methods?	I rarely implement practicum due to some factors, especially the limitation of time.	I rarely implement practicum.
What do you thing about the learning atmosphere in the classroom when you implement physic practicum learning method? Could you explain your answers?	Students are very enthusiastic.	Students are happy and motivated.
What difficulties do you face in organizing physics lessons in general and organizing physics practicum?	Lots of physics materials that should be taught in a relatively short time due to other teacher curriculum tasks. For practicum, the limitation of time become the main difficulty for practicum implementation.	Media for teaching theoretical and abstract physics concepts. The limitation of time to prepare practicum.
What do you think about the adoption of ICT in physics learning? Could you explain your answers?	ICT can be used to ease teachers in preparing learning media and tools.	ICT can be adopted to physics learning for creating learning environment more interesting for students.

4 Difficulties faced by students in understanding physics concepts

The overviews of difficulties faced by students in understanding physics concepts were obtained through interviews to students at grade 10, 11, and 12. The results are summarized in Table 4.

Table 4. Summary of interviews with students

Questions	Summarized Answers		
	Tenth Grade Students	**Eleventh Grade Students**	**Twelfth Grade Students**
Do you easily understand the physics concepts taught through physic classroom activities?	It depends on the types of physics concepts. For physics concepts that are related to the concepts I have learnt in junior high school, I can easily understand. However, senior high school physics concepts are difficult to understand.	The physics concepts in grade 11 are too mathematical, so they are mostly difficult to understand.	Sometimes, teachers focus students at grade 12 for passing final examination, so the learning process is oriented to solve physics problems dealing with final examination. Hence, I don't really understand the physics concepts taught by teachers.
What physics materials are you easy to understand?	Physics concepts dealing with daily phenomena.	Physics concepts I can easily find their examples.	Physics concepts that are not too mathematical.
What difficulties do you face in learning physics concepts?	Too many variations of physics problems that needs various mathematic formula.	I have no idea with physics problems that are too mathematical.	I can't imagine the real phenomena of physics concepts that are mathematical.
What efforts have you made to be able to understand the physics concepts?	Searching supporting physics materials from internet.	Following tutorial learning from private institution, watching YouTube.	Watching learning video from YouTube, consulting difficult materials with the teachers.
What do you thing if ICT is adopted to physics learning? Could you explain your answers?	It can improve student motivation to learning.	It can make learning better.	It can make me easily understand and master physics concepts and improve the quality of learning.

Discussion

Based on the analysis of the results of questionnaire dealing with the students' responses to physics learning, it can be seen that students are less motivated to learn physics. Students will be motivated to learn physics if teachers implement various learning methods and media, one of them is practicum method. Most students cannot well understand physics concepts having no real example phenomena and applications in daily life. Students face difficulties in understanding theoretical, mathematical, and abstract physics concepts. However, real and simulated phenomena of the physics concepts can help students to understand the concepts. The use of information of communication technology in physics learning potentially improves the physics concept understanding of students.

Based on the analysis of the results of questionnaire dealing with the students' responses to the potential implementation of physics learning using bifocal modeling-based practicum, it can be seen that physics practicum is considered to be able to improve physics understanding of students; help students to develop various skills, such as measuring, critical thinking, creative thinking, problem solving, and communication skills. Practicum can improve students' motivation to learn physics. However, physics practicum is rarely done. The use of information and communication technology (ICT) in physics learning can facilitate students to interact with phenomena dealing with the theoretical, abstract, and mathematical physics concepts, so students can be motivated to learn physics. Computer visualization is expected to help students to understand a certain physics concepts. Combining real experiment with simulated (virtual) experiment is also expected to enable students obtain holistic understanding of a given physics concept.

Based on the analysis to the results of interviews with teachers, it can be revealed that teachers make lesson plans. However, the implementation of physics learning do not exactly match with the lesson plans due to some factors, especially limitation of time, abundance of curriculum teacher tasks, limitation of supporting facilities. Hence, teachers often modify the lesson plans depending on existing condition. According to teachers, students are enthusiastic in learning physics when teachers show videos and animations or other interesting media, demonstrate a certain phenomenon, perform physics practicum, and discuss the application of physics in daily life. Teachers should repair or modify the learning methods to improve the concept understanding of students and equip students with 21st century skills needed to adapt in the 21st century life. Teachers consider that practicum method essential for physics learning. It can make students apply scientific methods and are motivated and enthusiastic in learning physics. However, practicum is rarely done due to some factors, especially the limitation of time. Teachers also consider that ICT can be adopted to physics learning for creating learning environment more interesting for students and can be used to ease teachers in preparing learning media and tools.

Based on the analysis to the results of interviews with students, it can be revealed that students face difficulties in learning physics especially for physics concepts that are too mathematical that need various mathematic formula. Students are relatively easy to understand physics concepts the examples of which are found in daily life and able to be simulated. Students try to improve their concept understanding of physics by optimizing digital learning resources, such as searching supporting physics materials from internet and watching YouTube. Moreover, students also follow tutorial learning from private institution.

Compared to the results of observations to physics learning process, relatively low motivation of students to learn physics may be caused by learning method implemented by teachers. In this case, teachers mostly used lecture method, in which students were involved in questioning and answering activities due to physics concepts presented in the textbooks. After that, students were served by some physics problems to be solved. Actually, the implementation of bifocal modeling practicum is adequately supported by the infrastructures in the observed school. It is because, the school has proportional computer laboratory consisting of 25 PCs connected by local area network (LAN), there is internet network which are well accessible from all classrooms, and all students (about 20 per class) have android mobile phones.

Conclusion

Based the analysis of the research data, it can be concluded that: 1) students are difficult to understand theoretical and mathematical physics concepts, but students consider that interacting with both real and simulated physic phenomena through practicum can improve students' motivation to learn physics and is able to improve physics understanding of students; help students to develop various skills, such as measuring, critical thinking, creative thinking, problem solving, and communication skills. 2) Teachers are difficult to organize a learning well because of some factors, among others limitation of time, abundance of curriculum teacher tasks, limitation of supporting facilities. 3) The adoption of information and communication technology in developing the tools of bifocal modeling-based practicum can be potentially helps students in understanding theoretical and mathematical physics concepts and teachers in organizing physics learning in a more advanced and quality way. 4) The infrastructures of the school are good enough to support the implementation of physics learning using bifocal modeling-based practicum. 5) Students and teachers are welcoming the applications of ICT to improve the quality of physics learning.

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