Doctoral Dissertation

The Effectiveness of Computer Simulations for Improving Indonesian Junior High School Students' Conceptual Understanding of Light and Optical Instruments

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ABSTRACT

Conceptual understanding is one of the competencies in the science education curriculum in Indonesia. This competency is a part of the science graduation standard indicated in Ministry of Education and Culture (MoEC) article number 20, the year 2016. Thus, conceptual understanding is needed by students for learning science successfully. However, students' conceptual understanding in Indonesia is low. According to Trends in International Mathematics and Science Study (TIMSS) in 2015, there were only 32% in the overall of Indonesian students who had the correct answer for a question that demands conceptual understanding ability on science. One of the factors that affect students' conceptual understanding is misconceptions. Misconceptions have occurred if the students' understanding of a concept differs from the scientific concept.

Previous studies on improving conceptual understanding suggested that the first step towards an effective learning process is to identify the misconceptions and employ effective teaching methods to overcome the misconceptions. One of the teaching methods to overcome students' misconceptions is using computer simulations in the learning process. Thus, the main objectives of this research were to investigate the effectiveness of computer simulations to improve students' conceptual understanding and to overcome students' misconceptions about light and optical instrument concepts.

Before investigating the effectiveness of computer simulations, this research was started by developing a two-tier multiple-choice test (TTMCT) to assess students' conceptual understanding as well as to investigate students' misconceptions of light and optical instrument concepts. The result from this test was twenty-two students' misconceptions about light and optical instrument concepts. These misconceptions were used to develop computer simulations about light and optical instrument concepts. The computer simulations programs were reviewed by six science teachers to obtain comments and suggestions for further improvement using a set of questionnaires, which consisted of 10 item questions with a 5-point Likert scale.

The sample of this study consisted of 264 junior high school students in 8^{th} grade from three public schools in Semarang city, Central Java Province, Indonesia. For this study, the sample was divided into two groups, the experimental and control group. For the experimental group (130 students), the learning process of light and optical instrument concepts was taught using the computer simulations. For the control group (134 students), the same concept was taught using science textbooks.

This study used a quasi-experimental design involving experimental and control groups. TTMCT measured students' conceptual understanding of light and optical instrument concepts. The TTMCT was administered to both the control and experimental group, first in the initial meeting before instructions and second in the seventh meeting after completing the instructions.

When the post-test scores were compared by means of the t-test to ascertain the effect of the computer simulations on the students' conceptual understanding, it was found that there was a statistically significant difference between the control and experimental groups [Mexp = 48.61, SDexp = 14.58, Mcon = 36.66, SDcon = 12.7, t = 7.099, sig < 0.05]. The results showed that computer simulations have a positive effect on students' conceptual understanding.

In conclusion, the computer simulations were found to improve students' conceptual understanding of the light and optical instrument concepts and had contributed to the higher achievement of the experimental group. The findings in this study showed that computer simulation is an effective teaching method to improve students' conceptual understanding and overcome their misconceptions about light and optical instrument concepts.

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DEDICATION

To my beloved family Hanida Trisnawati, Ahmad Nabiil Taqiyyuddin,
Afiqa Yasmine Charmaraiza and the rest of my family

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LIST OF ABBREVIATIONS

MoEC	Ministry of Education and Culture
MoRA	Ministry of Religious Affairs
TTMCT	Two-Tier Multiple-Choice Test

CHAPTER 1
INTRODUCTION

1.1. Overview of the chapter

This study aims to improve Indonesian junior high school students' conceptual understanding of light and optical instruments. Previous studies on improving conceptual understanding suggested that the first step towards an effective learning process is to identify the misconceptions and employ effective teaching methods to overcome the misconceptions. One of the teaching methods for overcoming students' misconceptions is using computer simulations in the learning process. A brief elaboration about these important issues commenced this introduction chapter. This chapter describes the background of the study, research objectives, research questions, significances of the study, and chapter list of dissertations. This introduction section offers a complete depiction of the whole study.

1.2. Background of the study

The Indonesian government has been making a series of alterations to the national curriculum during the 2000s, attempting to move from a content-based curriculum to a competency-based and from teacher-centered rote learning to student-centered active methods. The emphasis was on shifting the focus of education away from the memorization of facts and theoretical knowledge towards students being able to achieve competencies (MoEC, 2013). There are four core competencies which mandatory for all educational levels and all subjects, including science, namely spiritual, social, knowledge, and skill competencies. In particular of knowledge competencies, conceptual understanding is an inseparable part of the science concept. Conceptual understanding is one of the competencies in science learning in Indonesia. This competency is a part of the science graduation standard indicated in MoEC article number 20, the year 2016. Thus, conceptual understanding is needed by students for learning science successfully.

Students' conceptual understanding in Indonesia is low. The result of TIMSS' in 2015 showed that there were only 32% in the overall of Indonesian students who had the correct answer for a question which demands conceptual understanding ability on science (Martin et al., 2015). These facts indicated that the majority of Indonesian students' conceptual understanding needs to be achieved. The problem in conceptual understanding is difficult for students to make a connection with complex science phenomena in everyday life situation, for instance, light and optical instrument concepts.

Light and optical instruments is an important concept of everyday life (Yalcin et al., 2009) and it is used as the primary concept in many sciences area ranging from astronomy to zoology (Blizak et al., 2009). It is also an important science concept that is included in the curriculum of many countries. Furthermore, students' conceptual understanding in light and optical instruments has attracted the interest of researchers in different countries from early education to university level and beyond (Heywood, 2005; Yalcin et al., 2009; Blizak et al., 2009; Tural, 2015; Kaltakci-Gurel et al., 2016). However, based on the previous studies, various difficulties in dealing with abstract concepts were found in the learning process. Ling (2017) stated that light and optical instruments are a complex and difficult concept. Due to the importance and the difficulty of this concept, students have various misunderstandings and hence have developed misconceptions about this concept (Yalcin et al., 2009). The reasons behind misconceptions include the instructional methods used (Barke et al., 2009), science textbooks (Kaltakci & Eryilmaz, 2010; Gudyanga & Madambi, 2014), teachers' perceptions (Satilmiş, 2014; Erman, 2017) and even the students' everyday life experiences (Kaltakci & Eryilmaz, 2010; Widarti et al., 2016).

Misconceptions are developed by the students when their understanding of the scientific concept is not in line with those provided by scientists (Nakhleh, 1992; Barke et al., 2009; Allen, 2014). The previous study mentioned that misconceptions impede effective learning because the new knowledge cannot be integrated appropriately into students' cognitive structure due to the existing knowledge which is resistant to change (Taber, 2000; Ebenezeer et al., 2010). These studies also suggested that to develop conceptual understanding, students' misconceptions need modification in a process known as conceptual change (Chi & Roscoe, 2002; Ebenezeer et al., 2010). Previous studies on improving conceptual understanding suggested that the first step towards an effective learning process is to identify the misconceptions and employ effective teaching methods to overcome the misconceptions (Çepni et al., 2006; Cibik et al., 2008).

Overcoming students' misconceptions in science have been explored by previous researchers in the science education field. Research related to misconceptions had shown that traditional teaching methods are not effective for overcoming students' misconceptions (Saul & Redish, 1999; Jimoyiannis & Komis, 2001). One of the teaching methods for overcoming students' misconceptions is using computer simulations in the learning process

(Chen et al., 2013; Moosa, 2015; Ramnarain & Moosa, 2017). Previous study on the effectiveness of computer simulations for supporting science conducted by Smetana and Bell (2012) stated that computer simulations could help students to eliminate their misconceptions. Computer simulations provide interactive, authentic, and meaningful learning opportunities for students because it facilitates the learning of abstract concepts in science learning, such as light and optical instrument concepts.

Computer simulations have the potential to improve conceptual understanding more effectively for abstract scientific concept, and not easily accessed through direct observation (Zacharia and Olympiou, 2011). According to Scalise et al. (2011), computer simulations are used to model which is not easily observed in real life. Part of computer simulations impacts students' conceptual understanding can be attributed to the unique affordances that emerge from their multi-representational nature (Olympiou and Zacharia, 2012). For instance, an advantage of computer simulations compared to any other teaching methods is that they involve representations of abstract concept which are invisible in the physical world. As a result, computer simulations provide students through their multi-representational nature, which could lead to a deeper conceptual understanding of the scientific phenomenon.

A conceptual understanding is an important cognitive outcome in the science education field (Renken & Nunez, 2013). Students must be taught to develop a conceptual understanding that is aligned with the conceptual understanding accepted by the scientific community (Ausubel, 1963). Meaningful science learning requires conceptual understanding rather than memorization (Adadan et al., 2010). Meaningful learning requires knowledge to be constructed by the learners, not transmitted from the teacher to the students (Jonassen et al., 1999). To promote meaningful conceptual understanding, teaching strategies must be found to eliminate misconceptions. Meaningful learning activities helped students to cultivate deep learning and enhance conceptual understanding (Nieswandt, 2007). The conditions that affect the achievement of conceptual understanding apply to the process of learning science as well. Meaningful learning strategies allow students to implement from what they are learning. As students engaged in meaningful learning activities, they are also able to dispel misconceptions.

Misconceptions are also considered as one of the most important obstacles against meaningful learning (Kutluay, 2005). Meaningful and successful learning of science occurs when the misconceptions that students bring to the classroom are corrected (Bilgin, 2006).

Therefore, after students' misconceptions were identified, the teacher can help the students to achieve the understanding of scientific concepts. Helping students to develop a meaningful conceptual understanding of how the concept can be used in their daily lives is an aim of science education.

1.3. Research objectives

The general objective of this study was to investigate the effectiveness of computer simulations to improve students' conceptual understanding and overcome students' misconceptions about light and optical instrument concepts. The specific objectives can be described as follows:

1. To develop the Two-Tier Multiple-Choice Test (TTMCT) for measuring students' conceptual understanding and identifying students' misconceptions about light and optical instrument concepts.
2. To develop computer simulations for improving students' conceptual understanding and overcoming students' misconceptions of light and optical instrument concepts.
3. To improve students' conceptual understanding and overcome students' misconceptions using computer simulations of light and optical instrument concepts.

1.4. Research questions

The main research question was: What is the effect of computer simulations on improving students' conceptual understanding and overcoming students' misconceptions about light and optical instrument concepts? The sub-research questions were:

1. How to develop a two-tier multiple-choice test to measure students' conceptual understanding and identify students' misconceptions of light and optical instrument concepts?
2. What are the misconceptions about light and optical instrument concepts held by the students?
3. How to develop computer simulations for improving students' conceptual understanding and overcoming students' misconceptions about light and optical instruments?
4. What is the effectiveness of computer simulations to improve students' conceptual understanding and overcoming students' misconceptions using computer simulations about light and optical instruments?

1.5. Significances of the study

The significance of the study can be discussed concerning the theoretical and practical levels. At the theoretical level, this research can contribute to the educational research review about: (1) the effectiveness of computer simulations on conceptual understanding in science learning, (2) an overview about conceptual understanding in science education curriculum in Indonesia, and (3) factors affecting students' misconceptions about light and optical instrument concepts. At a practical level, this research provides science teachers in Indonesia with insight into teaching using technology such as computer simulations, particularly about light and optical instrument concepts. Furthermore, this research improves students' conceptual understanding and overcome students' misconceptions about light and optical instrument concepts. Moreover, this study covers the way for more research and studies in the future, such as the use of technology in science learning, which is in high demand, and the current trend in Indonesia.

1.6. Chapter lists of the dissertation

This dissertation is organized into seven chapters (Figure 1.1), and the synopsis of each chapter is given below.

Chapter 1: Introduction

Conceptual understanding in science learning has been the main concern of the researchers in the science education field. Students' conceptual understanding cannot be easily measured or observed. Teachers need to probe students' understanding before and after instruction. One of the factors that affect students' conceptual understanding is misconceptions. Misconceptions have occurred if the students' understanding of a concept differs from the scientific concept. Misconceptions are stable cognitive structures to change, affect students' conceptual understanding, and must be overcome so that students learn scientific concepts effectively. From the previous research, there are several methods to overcome students' misconceptions in science learning. One of the effective methods for overcoming misconceptions is using computer simulation in the classroom (Chen et al., 2013; Ramnarain & Moosa, 2017). Therefore, the purpose of this study is to investigate the effectiveness of computer simulations to improve Indonesian junior high school students' conceptual understanding and overcome students' misconceptions about light and optical instrument concepts.

Chapter 2: Literature Review

To achieve the purpose of this study, a literature review related to conceptual understanding, misconceptions, and computer simulations is needed. The first part discusses the definition of conceptual understanding in science learning and an overview of conceptual understanding in Indonesia. The second part discusses definitions of misconceptions, factors contributing to students' misconceptions in light and optical instruments in Indonesia, and previous research regarding misconceptions about light and optical instruments. The third part discusses definitions of computer simulations, advantages and disadvantages of computer simulations, and the effect of computer simulations in overcoming students' misconceptions and improving students' conceptual understanding. The literature review suggests that computer simulations play important roles in the science classroom, and it led the researcher to explore the effectiveness of computer simulations to achieve students' conceptual understanding and overcome students' misconceptions.

Chapter 3: Methodology

This chapter presents the research methods used to investigate the impact and effectiveness of computer simulations as a treatment in 8^{th}-grade junior high school students in learning light and optical instrument concepts. This study was conducted in three stages. The first stage is developing the Two-Tier Multiple-Choice Test (TTMCT) for measuring students' misconceptions about light and optical instrument concepts. The second stage is developing computer simulations based on students' misconceptions that have found in the pilot study. In the third stage, two groups of 8^{th}-grade students were exposed to different teaching methods. This stage was performed using a quasi-experimental design involving experimental and control groups. For the experimental group (N = 130), the learning process on light and optical instrument concepts was taught using computer simulations, and for the control group (N = 134), the same concept was taught using the traditional method. This chapter describes the research design, research instruments, samples of the study, data collection, and data analysis.

Chapter 4: Results 1 (Development of the Two-Tier Multiple-Choice Test to Assess Students' Conceptual Understanding about Light and Optical Instruments)

The first stage of this study is developing the Two-Tier Multiple Choice Test (TTMCT). A TTMCT about the concept of "light and optical instruments" was developed by the author. The test development procedure had three general steps: defining the content area of the test, identification of students' conceptions, and the development of the test. The final version of TTMCT consisted of 25 items question. To validate the TTMCT, a pilot study was conducted. For the pilot study, 95 junior high school students were involved. These students had completed unit on light and optical instruments. The main goal of the pilot study was to evaluate the effectiveness of the TTMCT regarding content coverage and language appropriateness. From the pilot test, it was identified that students needed about 80 minutes to complete the TTMCT. Two experienced science teachers and three science lecturers validated the content of the questions. The validators were provided with a description of tasks and the concept outline to evaluate the validity of the instruments. The validator commented that the content of the instruments covered almost 95% of the syllabus and suitable to be used. The language used was easily understood by the students. The reliability of the TTMCT was 0.76, indicating that the instrument has high reliability. Based on the data analysis, twenty-two misconceptions were identified. The results of the study showed that the TTMCT was effective in determining the students' misconceptions of light and optical instrument concept.

Chapter 5: Results 2 (Development of Computer Simulations to Overcome Students' Misconceptions about Light and Optical Instruments)

The second stage of this study is developing computer simulations. The computer simulations were developed according to the students' misconception, having assessed with TTMCT about light and optical instrument concepts. The computer simulations were developed using software Adobe Flash Professional CS6. Computer simulations were reviewed by six science teachers to receive comments and suggestions for further development using a set of questionnaires, which consists of 10 items with 5-point Likert scale. The items of the questionnaires were created to assess computer simulations from aspects of content explanation and its deepness, display, language use, content, curriculum, and students' misconception. The results of the study show that: (1) The computer simulations program is suited with the contents in the science curriculum, (2) The quality of computer simulations based on science teacher responses is in very good criteria. The results of the study showed that computer simulations are feasible for junior high school students to overcome misconceptions about light and optical instrument concepts.

Chapter 6: Results 3 (Improving Students' Conceptual Understanding Using Computer Simulations about Light and Optical Instruments)

The third stage of this study is implementing the computer simulations in the 8th-grade junior high school students. The purpose of this study was to investigate the effects of computer simulations on students' conceptual understanding of light and optical instruments. This study is a quantitative method using TTMCT for investigating students' conceptual understanding. For the experimental group (N = 130), the learning process on light and optical instrument concepts was taught using computer simulations, and for the control group (N = 134), the same concept was taught using the science textbooks. The TTMCT was administered to both the control and experiment group, once in the first week before instruction and again in the 4th week after completing the instruction. The learning process was conducted during regular science lessons and conducted twice a week. During the first week, the TTMCT was administered as a pre-test. After completing the instruction for three weeks (on the 7th meeting), the TTMCT was again administered as a post-test. For both groups, students' pre-test and post-test responses to the first tier and the combined tiers to each of the 25 items. When the post-test scores were compared by means of the t-test to ascertain the effect of the computer simulations on the students' conceptual understanding, it was found that there was a statistically significant difference between the control and experimental groups [Mexp = 48.61, SDexp = 14.58, Mcon = 36.66, SDcon = 12.7, t = 7.099, sig < 0.05]. The results of this study showed that computer simulations could improve students' conceptual understanding of light and optical instrument concepts.

Chapter 7: Conclusions and Implications

In conclusion, the key focus of this research was to explore the effectiveness of computer simulations in improving students' conceptual understanding and overcoming the students' misconceptions of light and optical instrument concepts. The findings of this study showed that computer simulations are an effective method to improve students' conceptual understanding and overcome students' misconceptions about light and optical instrument concepts. Despite the findings of this study showed that computer simulations are effective in overcoming misconceptions and improving students' conceptual understanding, the study exhibits several limitations. One of the limitations is that it lacks generalizability. Since the study involving a small number of participants, the findings from this study may not be generalized to the other contexts. According to the findings in this study, the recommendations for further studies are: (1) replicate this study to use computer simulations not only for teaching light and optical instrument concepts but also for all concepts in the science subject in the junior high school level; (2) the TTMCT was administered to 264 8^{th} grade students. However, the independent variables such as school type, gender, students' learning styles, socio-economic status did not take into this study. Therefore, a study that investigates the effect of these independent variables on the students' conceptual understanding can be studied.

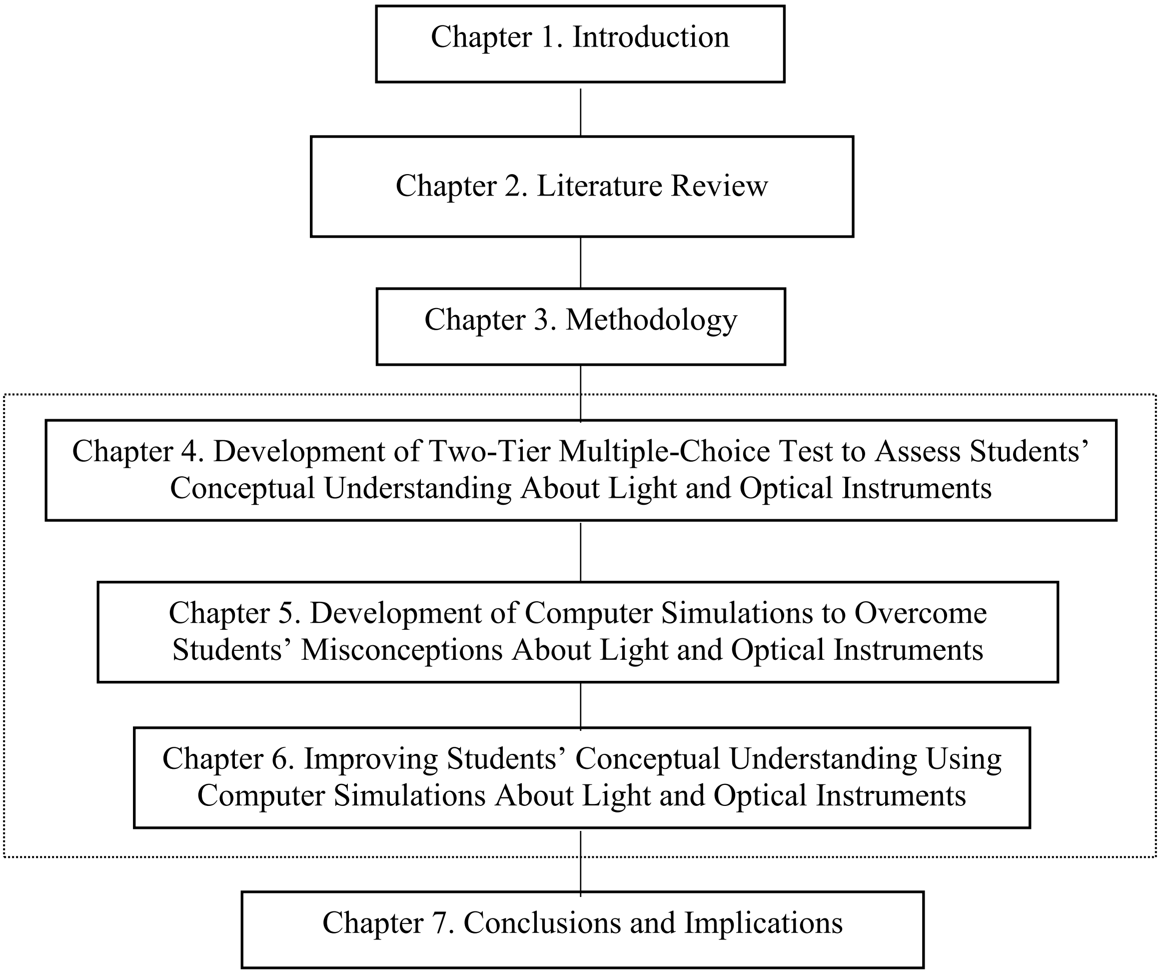


Figure 1.1. Chapter lists of the dissertation

CHAPTER 2
LITERATURE REVIEW

2.1. Overview of the chapter

The introduction section briefly discussed some background and research problems leading to the current study. This chapter offered elaboration and discussion of those backgrounds and problems by reviewing some literature from the previous study. This chapter attempts to explore research literature on the effectiveness of computer simulations to improve students' conceptual understanding and overcome students' misconceptions of light and optical instruments. It includes the definition of conceptual understanding, students' misconceptions, advantages of computer simulations, two-tier multiple-choice test, and light and optical instrument concepts. Finally, conceptual framework of this study is also included in this chapter.

2.2. Conceptual understanding

2.2.1. Definition of conceptual understanding

The word concept has many different meanings for science educators. Concepts are the construction of the human mind (Lawson et al., 2000; Konicek-Moran and Keeley, 2015). Concepts are like mental representations which in their simplest forms (Carey, 2000), such as light, energy, force, evaporation, respiration, heat, and acceleration. They are abstractions developed in the minds of people who tried to understand what was happening in their world. Concepts also consist of more than one word or a short phrase (Konicek-Moran and Keeley, 2015), such as light and optical instruments, conservation of energy, and food chain. Concepts imply meaning behind natural phenomena such as phases of the moon, transfer of energy, condensation, or cell division. When humans use a concept, there are usually some understandings of what associated with it.

The main goal of science education is teaching for conceptual understanding (NSTA, 2015). Conceptual understanding has been one of the primary goals for science studies, at all levels of formal education. However, educators seem to have taken the "conceptual understanding" as an intuitively meaningful and have not attempted explicit definitions (Nickerson, 1995; Holme, Luxford & Brandiet, 2015). Therefore, conceptual understanding can be defined variously, and previous scientific research showed the variability of these intuitive understanding of student conceptualization in science learning. Furthermore, the main benefit of articulating the various ways that science instructors view conceptual understanding is to bring into focus the greater whole of definition. The Summary of studies the elements of conceptual understanding can be seen in Table 2.1.

Table 2.1. Summary of studies elements of conceptual understanding

Authors and year of publication	Elements of conceptual understanding			
	relationship between the concepts	**reorganization of the existing knowledge or conceptual change**	**apply knowledge to solve the new problematic situations**	**in the meaningful learning condition**
Posner, et al. (1982)		√		
Novak & Gowin (1984)	√			
Roth (1990)				√
Heibert & Carpenter (1992)	√			
Tobin, Tippins & Gallard (1994)		√		
Cavallo (1996)				√
NRC (1996)	√		√	
Wiggins & Mctighe (1998)				√
Alao & Guthrie (1999)	√			
Duit (1999)		√		
Rittle-Johnson et al. (2001)	√			
Raviolo (2001)	√			
Novak (2002)				√
Darmofal, et al. (2002)	√		√	
Vamvakoussi & Vosniadou (2004)		√		
Gaigher, Rogan & Braun (2007)		√		
Nieswandt (2007)	√		√	
Puk & Stibbards (2011)	√			
Ellis (2013)			√	
NSTA (2015)			√	
Gale, et al. (2016)	√			

Firstly, the element of conceptual understanding is the students' ability to see the relationship between the concepts (Novak & Gowin, 1984; Heibert & Carpenter, 1992; NRC, 1996; Alao & Guthrie, 1999; Rittle-Johnson et al., 2001; Puk & Stibbards, 2011; Raviolo, 2001; Darmofal, et al., 2002; Nieswandt, 2007). Conceptual understanding described the richness of interconnections and relationships made between concepts and the structure which organizes those concepts (Novak & Gowin, 1984). According to Alao & Guthrie (1999), conceptual understanding is the relationship between concept. Concepts must be developed through processes that allow individuals to make new meaning by connecting past understandings and experiences with new ones (Puk &Stibbards, 2011). Conceptual understanding of the science concept is a complex phenomenon (Nieswandt, 2007). It combines an understanding of single concepts such as sunlight, chlorophylls, water, carbon dioxide, or of a more complex concept such as chemical energy, which following certain rules and models combines multiple individual concepts (e.g., photosynthesis), resulting in a new concept. Furthermore, conceptual understanding implies the ability to offer explanations and descriptions at the macroscopic level (experiments), the microscopic level (atoms, molecules, ions), and the symbolic level (symbols, formulas, equations), and the ability to establish appropriate connections among the three (Raviolo, 2011). Heibert and Carpenter (1992) described the process of understanding like a spider web with the "junctures of the web as pieces of information and the threads as connections or relationships" they go on to state "All of the nodes are ultimately connected, making it possible to travel between them by following established connections, some nodes are connected more centrally than others" (p. 69). The more knowledge is connected to other knowledge, and the stronger these connections become, the more likely a subject is to be understood.

The second element of conceptual understanding is described as the reorganization of the existing knowledge or called by conceptual change (Posner, et al., 1982; Duit, 1999; Tobin, Tippins & Gallard, 1994; Vamvakoussi & Vosniadou, 2004; Gaigher, Rogan & Braun, 2007) as propounded by the cognitive constructivist theory of learning. In science education research, researchers drew an analogy between the Piagetian ideas about accommodation and assimilation and the Kuhnian ideas about theory change in the history of science. The key is about how concepts change in the process of learning (Posner et al., 1982). In general, conceptual change expresses learning pathways from students' pre-instructional conceptions to the science concepts to be learned (Duit, 1999). Learning is built connections between what students already know or have experienced and the material they are learning (Vamvakoussi & Vosniadou, 2004). Learning a piece of new knowledge is integration into an existing knowledge framework (conceptual growth) or fundamental reorganization of existing knowledge to fit the new concept into the framework (conceptual change) (Treagust & Duit, 2008). Theory of Piaget (1985), explained how people use schemes to interpret new experiences concerning learners' existing schemata (mental concept) through a process of assimilation and accommodation. If new information is presented that fits into a structure, the student incorporates (assimilates) the information. If it does not fit into a structure, the student accommodates it. As a result, conceptual change describes the complex process of learning in domains where the pre-instructional cognitive structures of the learners have to be fundamentally restructured to allow understanding of the intended knowledge (Duit & Treagust, 2003; Vosniadou et al., 2001).

The third one, conceptual understanding might be interpreted students' ability to transfer knowledge and to apply the learned scientific phenomena in everyday life (NRC, 1996; Darmofal, et al., 2002; Nieswandt, 2007; Ellis, 2013; NSTA, 2015). Understanding science concepts requires that an individual integrates a complex structure if many types of knowledge, relationships between ideas, reasons for these relationships, ways to use the ideas to explain and predict other natural phenomena, and ways to apply them to many events (NRC, 1996). In other words, when students have an understanding of a concept, they can use it in areas other than in which they earned it and can state it in their words (NSTA, 2015). Furthermore, conceptual understanding is the ability to apply knowledge across a variety of instances or circumstances (Darmofal et al., 2002). This includes the ability to recognize new information as something different from someone's current understanding and to construct explanations to accommodate knowledge conflicts, or to seek relationships among diverse pieces of information (Chan, Burtis, & Bereiter, 1997). Bereiter and Scardamalia (2003) describe these knowledge-processing activities as ''knowledge building,'' which describes the highest form of conceptual understanding. Transferring knowledge was highlighted in the education literature (Franz, Hopper, & Kristonis, 2007; Sigler & Saam, 2006). Knowledge transfer has been defined as an attempt by an entity to copy a specific type of knowledge from another entity (Rogers, 1983). In other words, knowledge transfer is the transfer of knowledge to a location where it is needed and can be used. Transfer most likely occurs when the students know and understand underlying principles that can be applied to problems in new contexts.

Besides, the attainment of conceptual understanding was also supported by the inclusion of meaningful learning activities (Roth, 1990; Cavallo, 1996; Wiggins &Mctighe, 1998; Novak, 2002; Nieswandt, 2007). Meaningful learning described as the formulation of relationships between ideas, concepts, and information of science (Ausubel, 1968). Furthermore, meaningful learning is the meaning of new knowledge is constructed through its interaction with specifically relevant prior knowledge. A focus on meaningful learning is about the view of learning as knowledge construction in which students explore to make sense of their experiences (Roth, 1990). In constructivist learning, students involved in active cognitive processing, such as paying attention to relevant incoming information, organizing incoming information into a coherent representation, and mentally integrating incoming information with the existing knowledge. Meaningful learning requires knowledge to be constructed by the learners, not transmitted from the teacher to the students (Jonassen et al., 1999). Meaningful learning activities helped students to cultivate deep learning and enhance conceptual understanding (Nieswandt, 2007). The conditions that influence the achievement of conceptual understanding applied to the process of learning science as well. Meaningful learning strategies allow students to apply and make sense of what they are learning. As students engage in meaningful learning activities, they are also able to dispel misconceptions.

Finally, it can be concluded that the definition of conceptual understanding is the ability to see a relationship between the concepts, reorganization of the existing knowledge, and apply it to solve the new problematic situations which strengthened under the condition of meaningful learning.

2.2.2. An overview of conceptual understanding in Indonesian curriculum

The purpose of this part is to discuss the term "conceptual understanding" in the science education curriculum in Indonesia. The Indonesian government has been making a series of alterations to the national curriculum. The transformation of Indonesian curriculum can be seen as follows: curriculum 1947, curriculum 1964 (the study plans for elementary schools), curriculum 1968, curriculum 1973, curriculum 1975, curriculum 1984, curriculum 1994, curriculum 2004 (competency-based curriculum), curriculum 2006 (education unit level curriculum), and the latest is the curriculum 2013 (MoEC, 2013).

The National Education, which based on Pancasila and the 1945 Constitution of the Republic of Indonesia, was explained in Law Number 20-year 2003 about National Education System. The national education functions to develop the capability, character, and civilization of the nation for enhancing its intellectual capacity, and is aimed at developing learners' potentials so that they become persons imbued with human values which are faithful and pious to one and only God; who process morals and noble character; who are healthy, knowledgeable, competent, creative, independent; and as citizens, are democratic and responsible.

The Indonesian education system recognizes two different paths of education: school-based education and out of school education. Currently, Indonesia adopts a 6-3-3-4 school-based education system, which consists of 6 years of primary, three years of junior secondary, three years of senior secondary, and four years of tertiary education (see Figure 2.1).

In Indonesia, the education system has undergone a radical change in the twenty-first century (Berry, 2011). This reform has been marked by the implementation of school-based management, which includes reforming the national education objectives, decentralizing management from the government to the schools, and implementing the curriculum 2004, curriculum 2006, and curriculum 2013. In the past, the Indonesian education system placed a heavy emphasis on cognitive attainment by students (Yeom et al., 2002). The new curriculum aims at promoting students' ability to apply knowledge in real-life situations and calls for teachers to use classroom-based assessment to support learning.

In the era of decentralization, the government created Curriculum 2004, which was then handed over to an independent institution, the National Agency of Education Standard, to formulate core-subject competencies and develop the School-Based Curriculum in 2006. This was an era in which teachers had the authority to develop the curriculum based on the idea of "experiential and contextual learning". Within the implementation, there was criticism on the administrative approach to school curriculum quality assurance. Many teachers were overwhelmed in developing syllabi, which hinders them in improving their instructional practices. This motivated the government to implement Curriculum 2013, which emphasizes the mastery of core competencies by putting forward a "project-based and scientific approach". The government provides syllabi, student textbooks, and teacher handbooks. However, the initiative has been criticized by independent teacher associations because of hasty preparation and centralized and uniform approaches that may diminish teachers' authority.

Schools in Indonesia are divided into two groups, public schools, and private schools. Public schools are those organized by the Indonesian Government, especially the Ministry of Education and Culture (MoEC). Many public schools are Islamic schools or madrasah that are financed by the Ministry of Religious Affairs (MoRA). The education system in Indonesia has three formal levels of schooling, namely primary (Years 1-6), junior secondary (Years 7-9) and senior secondary (Years 10-12). Vocational schools (Years 10-12) that focus on several forms of vocational education, also exist at the third level. School education is compulsory for all students from Years 1 to 9.

School Age	Level of Education	MoRA		MoEC				
26 25	Higher Education	Islamic Doctorate Program (S3)		Doctorate Program (S3)	Second Professional Program (SP II)			
24 23		Islamic Master Program (S2)		Magister Master Program (S2)	First Professional Program (SP I)			
22 21 20 19		Islamic Graduate Degree Program (S1)		Graduate Degree Program (S1)	Diploma 4 Program (D4)	Diploma 3 Program (D3)	Diploma 2 Program (D2)	Diploma 1 Program (D1)
18 17 16	Secondary Education	*Madrasah Aliyah (MA)* Islamic General Senior Secondary School	*Madrasah Aliyah Kejuruan (MAK)* Islamic vocational SSS	*Sekolah Menengah Atas (SMA)* *General SSS*			*Sekolah Menengah Kejuruan (SMK)* Vocational SSS	
15 14 13	Basic Education	*Madrasah Tsanawiyah (MTs)* Islamic General Junior Secondary School		*Sekolah Menengah Pertama (SMP)* *General Junior Secondary School (GJSS)*				
12 11 10 9 8 7		*Madrasah Ibtidaiyah (MI)* Islamic Primary School		*Sekolah Dasar (SD)* Primary School				
6 5 4	Early childhood Education	*Bustanul Atfal/ Raudatul Atfal (RA/BA)* Islamic Kindergarten		*Taman Kanak-kanak (TK)* Kindergarten				
3 2 1 0								

Figure 2.1 School system in Indonesia based on law number 20-year 2003

Curriculum 2013 highlights two types of competencies: Core Competencies and Basic Competencies. Core Competencies are the main competencies used throughout the curriculum documents; they are spiritual, social, knowledge, and skill (MoEC, 2013). The text of the core competencies develops through all levels. Basic competencies are different and developed at each level and between subjects. Basic competencies include all knowledge and skills that must be taught in each subject at each level. The core competencies in the curriculum 2013 are levels of ability to achieve graduate competency standards, which a learner should have on each level. Table 2.2 shows the core competencies in science learning.

Table 2.2. Science subject core competencies in curriculum 2013

	Core Competency	Description
1.	Spiritual competency	Respect and appreciate the religion they believe
2.	Social competency	Respect and appreciate the honest behavior, discipline, responsibility, caring (tolerance, mutual assistance), mannered, confident, in interacting effectively with the social and natural environment within reach of the association and its existence
3.	Knowledge competency	Understanding and applying the knowledge (factual, conceptual and procedural) based on curiosity about science, technology, art, culture-related phenomena and events that can be seen with our eyes
4.	Skill competency	Processing, presenting, and reasoning in the realm of the concrete (using, analyzing, composing, modifying, and making) and the realm of the abstract (writing, reading, counting, drawing, and writing) in accordance with what they learned in school and other sources in the same viewpoint/theory

Basic competencies are the competencies of each subject for each class derived from core competencies. Basic competencies are a set of competencies that describe the minimum attitudes, skills, and knowledge that students need to achieve for each subject at the end of each semester of each grade. Table 2.3 shows the example of basic competencies in science subjects in grade 7^{th}, 8^{th}, and 9^{th}.

Table 2.3. Example of basic competencies of science subject in curriculum 2013

Grade VII		Grade VIII		Grade IX	
4.1	Understanding the concept of measurement of various magnitudes that exist in themselves, living beings, and the physical environment around as part of the observation, as well as the importance of the formulation of a standardized unit (basic) in the measurement	1.1	Understanding linear motion, and the influence of the force of the motion based on Newton's laws, as well as its application to the motion of living beings and the motion of objects in everyday life	1.1	Understanding the concept of atoms and their composition, ions and molecules, and its relationship with the characteristics of the materials used in everyday life
		1.2	Understanding and applying fluids characteristic to explain blood circulation and liquid transportation in the plant, osmotic pressure, diffusion in the respiration process in daily life	1.2	Understanding the importance of soil and the organisms that live in the soil for the sustainability of life through the observation
4.2	Understanding the classification procedure of living and nonliving	1.3	Understanding of vibration, wave, sound, and hearing,		

Grade VII	Grade VIII	Grade IX
organisms as part of scientific work, and classify a variety of living and nonliving organism based on observation patterns	and its application in animal sonar system in daily life.	
4.3 Understanding the characteristics of the substance, as well as physical and chemical changes in substances that can be used for everyday life	1.4 Understanding reproduction in plants, animals, and humans, the nature of heredity, as well as the survival of living things	
	1.5 Understanding the structure of the earth to explain the phenomenon of earthquakes and volcanoes and its relation to the diversity of rocks and minerals in some areas	

The teachers' and students' textbooks of science are the tools for implementing curriculum 2013 in the learning process. The teachers' and the students' textbooks have been prepared by the government based on Ministerial Regulation of Education and Culture No. 71 the year 2013. The students' textbooks are the learning source that contains: the title of the topic, information about core competencies that are appropriate to the topic in each chapter. Each chapter is equipped with a conceptual map, the students' activities such as experimental, non-experimental, discussion, exercise, summary, evaluation, and assignment for the students. In particular, the evaluation part in the students' textbooks contains questions for measure conceptual understanding in a chapter that has been studied by students.

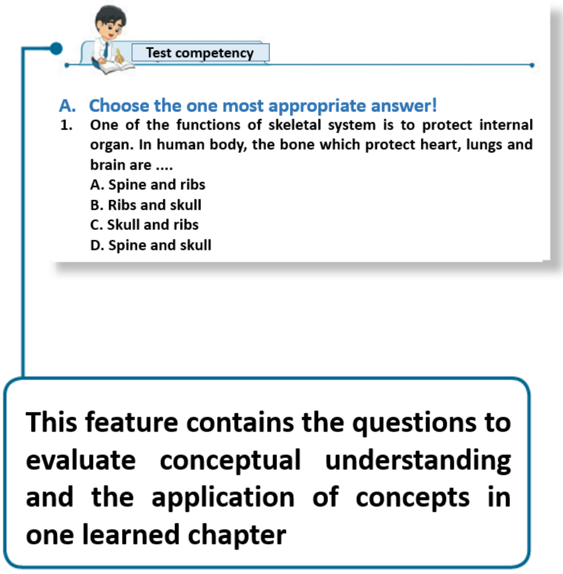


Figure 2.2. Evaluation for measure conceptual understanding in science textbooks

In measuring students' learning outcome for conceptual understanding, MoEC published science textbooks contains general guidance, process skills, and assessment in science learning. In the evaluation part, the textbooks use authentic assessment to measure learning outcomes. Based on the implementation guidelines of the curriculum 2013, it is stated that assessment is directed to measure students' competence stated in the curriculum, to measure conceptual understanding. Assessment can be performed by oral, tasks, daily test, mid-term test, final test, and national examination. Science tests that measure conceptual understanding focus on application, such as using the information to solve a problem or to make inferences about cause and effect relationships. The common methods to investigate conceptual understanding are asking students to recall information, labeling a diagram, explaining a scientific phenomenon, explaining why a particular instance is an example of the concepts, or distinguish between two similar concepts. Furthermore, the best way for students to improve their understanding of scientific concepts is to test them against their own experience (Soulios & Psillos, 2016).

2.3. Misconceptions

Conceptual understanding is one of the primary goals for science studies at all levels of formal education. Several studies have been conducted to investigate the students' conceptual understanding of science learning (Alao & Guthrie, 1999; Nieswandt, 2007; Puk & Stibbards, 2011; Konicek-Moran & Keeley, 2015). Students must be taught to develop a conceptual understanding that is aligned with the conceptual understanding accepted by the scientific community (Ausubel, 1963). The literature also indicates that various terms have been used to illustrate these ideas that contradict the scientific community. These ideas are known variously as misconceptions (Dykstra et al., 1992), alternative conceptions (Driver & Easley, 1978; Wandersee et al., 1994), naive conceptions (Champagne et al., 1983), and preconceptions (Ausubel, 1963). Analysis of the differences of these terms indicates the existence of a subtle distinction in the use of these terms (Wandersee et al., 1994). Hence, similar to various other previous studies, the term "misconceptions" will be used in this study.

Misconceptions are deemed to have occurred if the students' understanding of a concept differs from what is understood by the scientific community (Nakhleh, 1992). Besides, misconceptions are a stable cognitive structure that affects students' understanding of scientific concepts (Taşlıdere, 2013). Misconceptions can occur in students' understanding of scientific concepts as well as in their organization of scientific knowledge

(Thompson & Logue, 2006). Misconceptions are sturdy and resistant, so they are difficult to replace with new, true understandings; they consistently influence the effectiveness of further learning (Hammer, 1996; Ozmen, 2004; Taber, 2009).

Meaningful and successful learning of science occurs when the misconceptions that students bring to the classroom are corrected (Bilgin, 2006). Therefore, after students' misconceptions were identified, the instructor or teacher can help the students to achieve the understanding of scientific concepts. Helping students to develop a meaningful conceptual understanding of how the concept can be used in their daily lives is an aim of science education.

Students develop misconceptions from various resources. Misconceptions contrast with scientific concepts, and most authors frequently refer to some factors such as influence from everyday life experiences (Abraham et al., 1992; Smith et al., 1994; Kaltakci & Eryilmaz, 2010; Suniati et al., 2013; Widarti et al., 2016), teachers (Kaltakci & Eryilmaz, 2010; Gudyanga & Madambi, 2014; Satilmiş, 2014; Erman, 2017), reference book or textbooks (Devetak, Vogrine, & Glazar, 2007; Kaltakci & Eryilmaz, 2010; Gudyanga & Madambi, 2014; Widarti et al., 2016; Erman, 2017) and confusion of everyday language used as factors contribute to misconceptions (Osborne et al., 1983; Abraham et al., 1992; Bahar, 2003; Tyson, Treagust & Bucat, 1999; Suniati et al., 2013; Boz, 2006; Erman, 2017). The summary of studies the factors that contribute to misconceptions in science learning is presented in Table 2.4.

Table 2.4. Summary of factors contributing to students' misconceptions.

Author(s)	Factors contributing to misconceptions			
	Everyday experiences	Language used	Teacher	Textbooks
Osborne et al., 1983		√		
Abraham et al., 1992	√	√		
Smith et al., 1994	√			
Bahar, 2003		√		
Boz, 2006		√		
Devetak et al., 2007				√
Tyson et al., 1999		√		
Kaltacky & Erylmaz, 2010	√		√	√
Suniati et al., 2013	√			√
Gudyanga & Madambi, 2014			√	√
Satilmiş, 2014			√	
Widarti et al., 2016	√			√
Erman, 2017		√	√	√

Based on Table 2.4, four major factors contribute to students' misconceptions in science learning, namely everyday experiences, language used, teachers, and textbooks. These factors are shown in Figure 2.3.

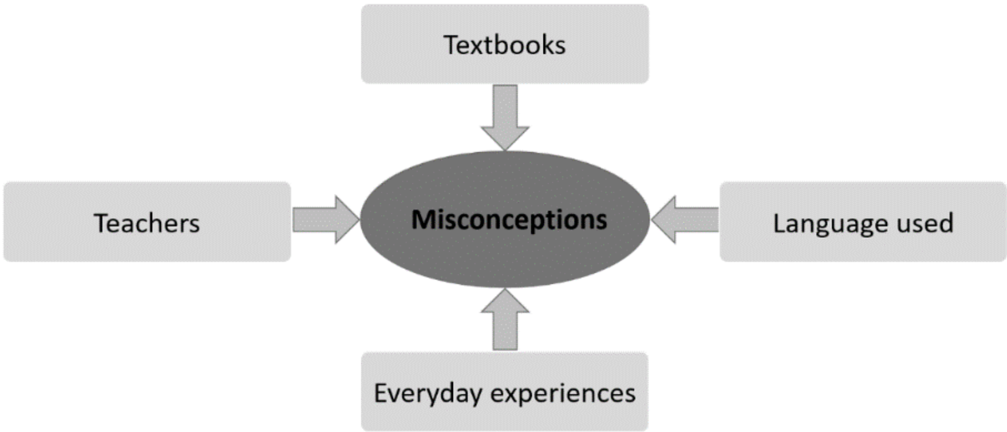


Figure 2.3. Factors contributing to students' misconceptions in science learning

2.3.1. Analyzing factors contributing to students' misconceptions in light and optical instrument concepts

Although light and optical instruments are an everyday phenomenon that students observe, numerous researchers have reported that students often showed learning difficulties and held an unscientific understanding of this concept. According to Ling (2017), light and optical instruments are complex concepts that lend itself to misconceptions among teachers and students. A review of the literature on this concept has shown various difficulties in dealing with abstract concepts in the learning process. Because of these difficulties, students tend to develop misconceptions about light and optical instruments. With careful study of previous literature, the main possible factors that contribute to students' misconceptions of light and optical instrument concepts are discussed in this section.

a. Everyday experiences

Students' interactions with the environment in daily life experiences confuse the students (Smith et al., 1994; Agnes et al., 2015). The close relation of light and optical instrument concepts to the everyday experiences of students may be a source of misconceptions on this topic (Kaltakci & Eryilmaz, 2010). Students get familiar with their environment, and they spend a lot of time outside of school. They have their explanations of meanings of things in the world around them. Mainly, such explanations do not match with scientific meaning. The students' understanding of the science concept based on the interaction with the surrounding environment and embedded with the daily life experience.

In an everyday sense, "light" can be defined as an area that is illuminated, e.g., we need more light in here, or is it light outside yet? Therefore, students understanding light as being a general quality of a location which conflicts with the scientific idea of light as a form of energy that travels from one place to another (Allen, 2014). In light and optical instrument concepts, students in Indonesia provide an example of the properties of light based on their daily experiences. One misconception from previous research was "light is an electromagnetic wave and has infinite speed." Based on this misconception, students think that light is an electromagnetic wave and has infinite speed because they taught that the sun is shining every second. The fact is light needs around 8 minutes 20 seconds to reach on the earth from the sun.

b. Language used

Students faced difficulties when scientific words were used in everyday language. The language used by individuals may be responsible for students' misconceptions (Osborne et al., 1983; Boz, 2006). Many words in light and optical instruments are difficult for students, for instance, "light'. Students commonly speak that light is something that makes vision possible. However, in science, the definition of light is electromagnetic radiation of any wavelength that travels in a vacuum with a speed of 299,792,458 meters per second; specifically: such radiation that is visible to the human eye.

Students also have the misconceptions that color is a property of the object rather than light. In daily language, saying "the table is red" instead of "the table is reflecting red light" may be considered as the source of misconceptions (Kaltakci & Eryilmaz, 2010). The factors that impede understanding of this concept are the light concept is abstract for the students, and the characteristic of light (its speed, wavelength, color, etc.) is beyond the perception of student's senses. Furthermore, many terms in the light concept are difficult for students; for instance, reflection, refraction, and dispersion. In Indonesia, the misconception found from previous research is convex mirror can make an image larger than the object (Agnes et al., 2015). Students think that the characteristic of the magnification image of a convex mirror is similar to the convex lens. Many difficult and complex words in light and optical instrument concepts provided in Indonesian textbooks, such as real image, virtual image, magnification, etc. Due to the difficulty and complexity of light and optical instrument concepts, students have developed misconceptions about this concept. Table 2.5 provides a summary of difficult words of light and optical instrument concepts.

Table 2.5 Difficult words in light and optical instrument concepts (MoEC, 2017)

Subtopic	Difficult words
1. The properties of light	Reflection, refraction, electromagnetic wave
2. The formation of images in mirrors and lenses	Focal length, convergent, divergent
3. The formation of images in optical instruments	Real image, virtual image, magnification
4. The structures and function of human eyes	Cornea, eye lens, pupil, iris, punctum proximum, punctum remotum
5. Eye disorders and the solutions for each disorder	Myopia, presbyopia, hypermetropia

c. Teachers

Science learning is enacted in classrooms, mainly through the interactions between teachers-students, students-students, students-materials, and teachers-materials. In the science classroom, the teacher is perceived to be the dominant figure to provide the direction for learning. Thus, the roles played by science teachers are necessary for shaping students' experiences of science learning and sometimes teachers are propagating misconceptions to students.

Previous research in Indonesia founds several misconceptions from science teachers. For instance, teachers think that the property of an image formed by a plane mirror is real (Saputri & Nurussaniah, 2015). The correct concept is that the property of an image formed by a plane mirror is virtual because teachers think that the eyes can see the images. The fact, virtual images are images that are formed in locations where light does not reach. Another example is teachers think that the angle of incidence formed between the incident ray with the mirror surface (Saputri & Nurussaniah, 2015). The correct concept is the angle of incidence formed between the incident ray and normal line.

Teachers propagate misconceptions because of their inability to communicate effectively with students (Gudyanga & Madambi, 2014). In some cases, teachers may be unaware of student's difficulties and fail to take appropriate methods in presenting specific ideas to students (Kaltakci & Eryilmaz, 2010). Furthermore, Satilmiş (2014) stated that students had misconceptions due to ineffective teaching methods, especially when the teachers followed the traditional method. Teacher fails to present abstract concepts appropriately, either by visualization or analogy to help students understand the concepts

(Treagust et al., 2003). The reasons why teachers propagate misconceptions can be seen in Table 2.6.

Table 2.6. The reasons why teachers propagate misconceptions

Why teachers propagate misconceptions?	Studies
1. Teachers inability to communicate effectively with students	Gudyanga & Madambi, 2014
2. Teachers fail to connect a various concept	Ibnu, 1989
3. Teachers fail to appropriately present abstract concept, either by visualization to help students understand the material	Treagust et al., 2003
4. Teachers also have misconceptions	Gudyanga & Madambi, 2014
5. Teachers inability to implement various teaching methods	Gudyanga & Madambi, 2014; Taber 2003

Teachers' misconceptions are also one reason for students' misconceptions (Gudyanga & Madambi, 2014). It means that there is the possibility of the teachers transferring their misconceptions to the students since they are the main source of instruction. During their training, when teachers learn abstract concepts without clear understanding, they end up disseminating their misconceptions to their students. Therefore, science teachers must have a clear conceptual understanding of the science concept in each learning activity.

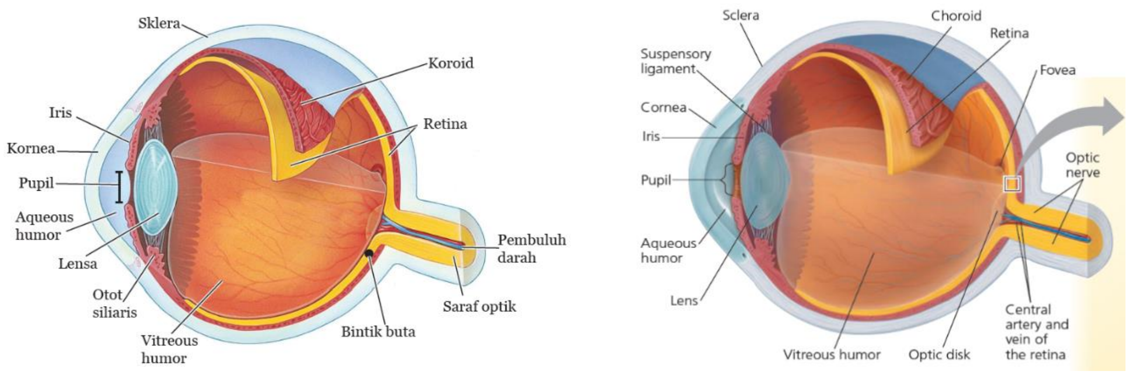
d. Textbooks

Textbooks are a tool used in the teaching-learning process and a guide for teachers and students. Textbooks have an important role in students' construction of conceptual understanding. However, textbooks may also serve as a cause of misconceptions (Devetak, Vogrine, & Glazar, 2007; Gudyanga & Madambi, 2014). The unclear figure in the textbook is one of the reasons misconceptions at the submicroscopic level (Devetak, Vogrine, & Glazar, 2007). Similarly, textbooks do not always provide complete and correct information or explanations (Gudyanga & Madambi, 2014). Finally, textbooks present the information in the symbol which is difficult to understand (Gabel, 1998; Nyachwana & Wood, 2014). The reasons why textbooks can cause misconceptions can be seen in Table 2.7.

Table 2.7. The reasons why textbooks cause misconceptions

Why textbooks cause misconceptions?	Studies
1. Textbooks are using confusing language	Devetak, Vogrine, & Glazar, 2007; Gudyanga & Madambi, 2014
2. Textbooks are presenting oversimplified materials and misleading information	Gilbert, 2003; Taber 2003
3. Textbooks are presenting information or ideas which difficult for students	Gilbert, 2003; Taber 2003
4. Textbooks are using symbols that are difficult to interpret	Gabel, 1998; Nyachwana & Wood, 2014
5. Textbooks are using terms that are unfamiliar to students	Taber, 2003

In Indonesia, science textbooks are provided by the MoEC (Ministry of Education and Culture). These textbooks are perhaps the only learning materials available and used in most Indonesian Schools. In light and optical instrument concepts, there are some unclear figures that are presented in the textbooks. For instance, in the parts of the human eye, the Indonesian textbooks represent the unclear image of the pupil and aqueous humor (Figure 2.4 a). Meanwhile, in a biology book by Campbell (2017), pupil and aqueous humor are shown by a clear picture (Figure 2.4 b).



(a) (b)

Figure 2.4. (a) Parts of the human eye (MoEC, 2017) and (b) Parts of the human eye (Campbell et al., 2017).

Students in Indonesia are difficult to explain the process of the eye's accommodation. Eye's accommodation is the ability of the eye to change its focus from distant to near objects. This process is achieved by the lens changing its shape (Campbell, 2017). The process of the eye's accommodation is too abstract for students and tends to cause the misconceptions. This misconception occurs because the textbooks provide static illustrations related to the function of the human eye (Figure 2.5).

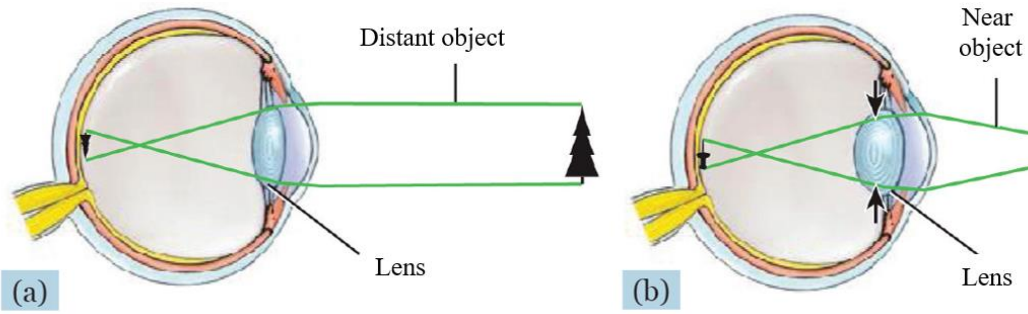


Figure 2.5 Accommodation of the human eye (MoEC, 2017).

Based on science textbooks, the plane mirror reflects 100% of the light will reflect the light that shines on it. In fact, no mirror reflects 100% of the light that shines on it. Good mirrors reflect 95% of the light that is incident on them. The remaining light 5% is absorbed and converted to heat (Pompea et al., 2007). The accurate information, illustration, and clarity of the contents in the textbooks are important in the learning process. Therefore, textbooks should be reviewed by experts and should be carefully chosen in order to facilitate students' learning and to prevent misconceptions. Furthermore, textbooks can help students to understand the science concept, particularly light and optical instrument concepts.

2.3.2. Remediations of misconceptions

Past studies on improving conceptual understanding of science suggest that the first step towards an effective teaching and learning process is to identify the misconceptions and employ effective teaching strategies to remediate the misconceptions (Çepni et al., 2006; Çibik et al., 2008). To promote meaningful learning, teaching strategies must be found to eliminate misconceptions. Research related to misconceptions had shown that traditional teaching strategies are not effective for overcoming students' misconceptions (Saul & Redish, 1999; Jimoyiannis & Komis, 2001). The process of correcting students' misconceptions depends on not only the delivery of new knowledge but also the gradual integration of new concepts related to students' existing conceptual structures (Vosniadou, 2002). New instructional methods must be developed to support students in actively constructing and adapting their knowledge (de Jong & Van Joolingen, 1998).

Posner et al. (1982) stated that conceptual change develops through cognitive conflict and comprises four conditions before students can replace their existing misconceptions: (1) Students must become dissatisfied with their existing knowledge so that accommodating new ones may be easier, (2) The new concept must be intelligible so that students can understand the concepts and make sense to them, (3) The new concepts must be plausible so that students must emerge to have the capacity to solve the problems and be consistent with past experiences, and (4) The new concepts must be fruitful, it means that the new concept should have the capacity to solve the problems or predict phenomena more easily than the existing concept.

Overcoming misconceptions require teaching strategies that provide chances for students to reveal their pre-concepts and dissatisfaction with their concepts. Several teaching strategies have been tried to overcome students' misconceptions, and some results of such trials have revealed significant effectiveness in dealing with students' misconceptions.

From the previous research on students' misconceptions in science learning, we found most strategies for overcoming students' misconceptions. These strategies focused on repairing and changing misconceptions when they have already been formed or identified. The strategies are most frequently adopted are: using learning cycle approach in the classroom (Osman, 2017), utilizing concept cartoon (Yong & Kee, 2017), using constructivist-based approach (Awan, 2013; Ling, 2017), using drawing analysis (Dikmenly, 2010), using inquiry-based learning (Ray & Beardsley, 2008; Heng & Karpudewan, 2017), using cooperative learning approach (Bilgin & Geban, 2006; Manolas & Leal, 2011), using analogy activity (Çalik et al., 2009), and using computer simulation (Chen et al., 2013; Moosa, 2015; Ramnarain & Moosa, 2017).

2.4. Computer simulations

Technological advances increasingly brought digital instructional technologies into the science classroom. One of the technological advances is a computer simulation. Computer simulations are computer-generated dynamic models that present theoretical or simplified models of real-world components, phenomena, or processes (Bell et al., 2008). In line with this, simulation is a representation or model of an event, object, or some phenomenon (Thompson, Simonson, & Hargrave, 1996). Simulations are used to model that which is not easily observed in real life or are used in teaching situations where simulation offers advantages (Scalise et al., 2011). Computer simulations are programs that allow the learners to interact with a computer representation of either (a) a model of the natural or physical world or (b) a theoretical system (Weller, 1996). Simulation provides learnercentered environments that allow students to explore systems, manipulate variables and test hypotheses (Windschitl, 1998). Furthermore, these programs can be used as demonstrations by teachers, or they can be used directly by the students to explore various phenomena that would not be readily available under normal situations. Simulations also provide learners with realistic experiences from which to gain and manipulate knowledge to understand better the relationship between the concepts being investigated. Simulations can combine animations, visualizations, and interactive laboratory experiences.

By combining animations and visualizing science concepts, simulations can support the development of insight into complex phenomena (Akpan, 2001). Simulations can be used in class when equipment is not available, or when it is not practical to set it up (Wieman et al., 2010). Another application of simulations is for doing experiments that would otherwise be impossible to do. Variables can easily be changed in simulations in response to students' questions, where this is not always possible with real equipment. Students can practice laboratory techniques before engaging in lab experience with real equipment (Akpan, 2001). They can also practice with simulations at home to repeat or extend classroom experiments for additional clarification. The studies that compared the application of simulations with traditional learning seem to indicate that traditional learning can be successfully improved by using simulations. Within traditional instruction, learners can be a useful add-on, for instance, serving as pre-laboratory exercise or visualization tools. Chang, et al. (2008) proved that learning by using simulation in optical lenses topic leads to a significantly greater improvement in learning outcomes in comparison with traditionally laboratory practices.

The use of computer simulations in the classroom has a positive finding on conceptual understanding (Ramasundarm, et al., 2005; Abdullah & Syarif, 2008; Plass, et al., 2012; Nowak et al., 2013; Sarabando et al., 2014). The use of computer simulations also helps students to understand difficult science concepts (Plass, et al., 2012; Webb, 2012; Sarabando et al., 2014). The Summary of studies the advantages and disadvantages of computer simulations can be seen in Table 2.8.

Table 2.8. Summary of studies the advantages and disadvantages of computer simulations

No	Simulations in Science Learning	Studies
	Advantages	
1	Simulations work that will improve the understanding of science concepts, not only students' understanding, but also pre-service teachers' understanding.	Liu & Hmelo-Silver, 2009; Ryoo & Linn, 2012; Bell, Maeng, & Binns, 2013; Nielsen & Hoban, 2015
2	The use of simulations helps students to understand diffficult science concepts	Plass, et al., 2012; Webb, 2012; Sarabando et al., 2014
3	Simulations can make abstract science phenomena more accessible and visible to students.	Muller, Sharma, & Reimann, 2008; Stieff, 2011; Ryoo & Linn, 2012
4	Simulations can animate dynamic changes in scientific processes that are difficult to infer from static illustrations found in the textbooks	Marbach-Ad, Rotbain, & Stavy, 2008; Ryoo & Linn, 2012
5	Simulations help students visualize the phenomenon that might otherwise be difficult to depict	Chang, Quintana, & Krajcik, 2010
6	Simulations can help students to generate their own mental models and understand new concepts	Buckley, 2000; Treagust, et al. 2002; Abdullah & Syarif, 2008; Landriscina, 2009; Quellmalz et al., 2012; Nowak et al., 2013;
7	Simulations work to increase student engagement to learn science	Davies 2002; Shellman and Turan, 2006; Honey & Hilton, 2011
8	Simulations help students to overcome misconceptions	Chen et al., 2013; Moosa, 2015; Ramnarain & Moosa, 2017
	Disadvantages	
1	Lack of realism (in a real environment, people can feel and taste, while in the simulation this cannot happen)	Sadideen et al., 2012
2	Students have time flexibility to think and react in problem-based scenarios: there is no stress for quick thinking as in real situations	Byrne et al., 2010
3	Computer simulations do not do much develop the skills of handling laboratory equipment	Karlsson, Ivarsson, & Lindström, 2013

The first reason for using computer simulations concerns the need to understand the complex phenomenon in science, for instance, DNA, molecular structure, atom, or molecule. Hmelo, Holton, and Kolodner (2000) suggested that structures are often the easiest aspect of a complex system to learn; in molecular genetics especially, understanding the structure of molecules such as DNA and RNA is crucial to comprehend their functions. Simulations, in this case, can help to organize the small pieces of information into large pieces of information, reducing the amount of memorization required by increasing the logical connections between ideas (Tversky et al., 2002). Simulation allows learners to view and interact with models of phenomena and processes (Plass et al., 2012).

Visualization of phenomena through simulation can contribute to students' understanding of the science concepts at the molecular level by attaching mental images to the concepts (Abdullah & Syarif, 2008). Lambert and Walker (1995) stated that a mental model is an understanding and interpretation of an individual's existing concept, which is formed and reformed by experiences, beliefs, values, socio-cultural histories, and prior opinions. Mental models affect how interpreting new concepts and events. Many topics in science require students to generate their mental models and students are aware that physical representations can help them to create their mental models and understand new concepts (Treagust, et al. 2002). To solve this problem, teachers routinely use models and representations to assist students in constructing their mental models, for instance, using simulation. By using the simulation, they can see a concrete situation that helps them to build a mental model. Mental models, like prior knowledge, influence students' perceptions of phenomena and students' understanding (Buckley, 2000). Using simulations, students can represent their understanding of scientific phenomena and mental model construction (Abdullah & Syarif, 2008; Quellmalz et al., 2012; Nowak et al., 2013). Similarly, simulation is the most suitable method when the learning objective requires a restructuring of the students' individual mental models (Landriscina, 2009). Restructuring their own mental model can help students to increase the conceptual understanding of the science concepts.

The second reason for using computer simulations concerns the need to understand the learned scientific concepts of scientific phenomena in an everyday life situation. Some scientific phenomena in science occur very fast and take place in multiple locations; for instance, cell division. Simulation can facilitate the development of students' evaluation skills to understand the phenomena at the molecular level (Sanger, Brecheisen, & Hynek, 2001). Starting, stopping, and replaying a simulation can allow focusing on specific parts and actions. A simulation that allows zooming and control of speed are even more likely to be facilitating (Tsui & Treagust, 2004; Tverssky et al., 2002). Simulations may be used to show students scientific phenomena that cannot be observed easily in real-time. For example, they can allow students to see things in slow-motion, such as lightning or speeded up, such as earth revolution. They are used to model phenomena that are invisible to the naked eye, such as cell division. The simulation utilizes situations that require several repetitions of an experiment, for example rolling a ball down a slope while varying the mass, the angle of inclination, or the coefficient of friction.

The third reason for using computer simulation concerns the need to understand emphasizing breadth and depth of scientific knowledge. Computer simulations can bridge this breadth and depth of students' knowledge because simulations have the potential to make learning abstract concepts more concrete (Ramasundarm, et al., 2005). Simulations can make abstract science phenomena more accessible and visible to students. For example, understanding science phenomena such as the circulatory system are difficult for some reasons. It is a complex interactive system that ranges in scale from the heart or blood vessels visible through the skin to blood cells circulating in capillaries much smaller than the human visual range. Simulation has the potential to make abstract scientific concepts, such as the circulatory system, more accessible and visible to students. Muller, Sharma, & Reimann (2008) explained that simulations allow learners to represent visually and dynamically important concepts that would otherwise be invisible. They can provide detailed representations of unobservable science phenomena (Stieff, 2011; Ryoo & Linn, 2012). They can also animate dynamic changes in scientific processes that are difficult to infer from static illustrations found in the textbooks (Marbach-Ad, Rotbain, & Stavy, 2008; Ryoo & Linn, 2012). In particular, simulations or animations can help students visualize the phenomenon that might otherwise be difficult to depict (Chang, Quintana, & Krajcik, 2010). Thus, the benefit from simulations are making science abstract concept more accessible, visible, and can help students to understand science concepts. When students are unable to observe or experience abstract science phenomena directly, simulation can play a crucial role in helping them understand those phenomena.

Computer simulations work to improve understanding the concept of science, not only students' understanding but also pre-service teachers' understanding. For example, Bell & Trundle (2008) stated that well-designed simulation combined with appropriate instruction effective in improving preservice teachers' conceptions of moon phases. In addition, simulation also influences pre-service teachers' and middle school students' learning to develop a deep understanding of a complex science system (Liu & Hmelo-Silver, 2009). Furthermore, creating simulation also enabled pre-service science teachers to develop more elements to contribute to their understanding of science concepts (Nielsen & Hoban, 2015; Bell, Maeng, & Binns, 2013). Creating simulations enabled the preservice teachers to develop more elements to contribute to their understanding of the science concept. Creating the multiple representations presented many opportunities to have their alternate conceptions and elements that underpinned the concepts challenged, discussed, negotiated, and revised. Importantly, the stop-motion construction process was halted several times enabling preservice teachers to check, review, and revise information (Hoban & Nielsen, 2014). Thus, the development process enables an ongoing interplay between existing knowledge. Further, the process of developing simulations as a teaching resource has the potential to help them consider relationships between different representational and develop more sophisticated understandings.

Other benefits from the simulations do not only work on conceptual understanding but also to increase student engagement to learn science. Shellman and Turan (2006) have reported an improvement in student's participation, motivation, and preparation for learning science through simulation. Moreover, simulations have the potential to advance multiple science learning goals, including motivation to learn science, understanding of the nature of science, science process skills, scientific discussion and argumentation, and identification with science and science learning (Honey & Hilton, 2011). Supporting this idea, Davies (2002) suggest that for successful students' engagement with computer simulations, the learning must be authentic and meaningful, students should work on group projects where they can share their understanding.

Remember that computer simulations are tools to support science learning. As with other educational tools, the effectiveness of simulation is limited by how they are used. Instructional strategies proven to support meaningful learning should be adhered to when using computer simulations. Students should be actively engaged in the acquisition of knowledge and encouraged to take responsibility for their own learning.

2.5. Two-tier Multiple-Choice Test (TTMCT)

Students' conceptual understanding cannot be easily measured or observed. Teachers need to probe students' understanding before and after instruction. In order to measure students' conceptual understanding of several concepts in a science subject, different diagnostic tools have been developed and used. Among them, interviews, open-ended tests, and multiple-choice tests are found to be the ones commonly used in science education research (Gurel et al., 2015).

Multiple-choice tests have been used for measuring students' understanding of concepts as they enable a large number of students to be sampled in a given amount of time as compared to time-consuming interviews. These tests are also easy to administer and score, and the results obtained are also easily processed and analyzed (Peterson, Treagust, & Garnett, 1989; Taber, 1999; Tan & Treagust, 1999). However, multiple-choice questions may not always indicate students' understanding or detect students' misunderstanding for a particular concept (Griffard & Wandersee, 2001). The use of a two-tier diagnostic test (Treagust, 1988) has provided a better way to improve how students' conceptions can be evaluated.

A two-tier diagnostic test was first developed with items specifically designed to identify alternative conceptions and misunderstandings in clearly defined content areas of science. Since that time, a number of two-tier tests have been developed and reported in the literature (Treagust & Chandrasegaran, 2007). Two-tier diagnostic tests have been regarded as an effective assessment tool to determine students' conceptual understanding (Treagust, 1988; Odom & Barrow, 1995; Chen et al., 2002; Lin, 2004; Cengiz, 2009; Sesli & Kara, 2012; Adadan & Savasci, 2012).

In a two-tier test, the first tier asks a student to choose about some specific concept; and the second tier asks the student about the reason or explanation for choice in the first tier. In Treagust's (1988) method for the scoring of two-tier items, each item was considered to be correctly answered if a student's choice of the first tier (content knowledge) and the second tier (the reason for the first tier) were both correct. With this stringent method of scoring, the chances of obtaining a correct answer by guessing were very low.

Two-tier tests also have been used by previous researchers to identify students' misconceptions in science learning (Treagust & Haslam, 1986; Treagust, 1988; Griffard & Wandersee, 2001; Kanli, 2015; Yusrizal & Halim, 2017), and particularly in light and optical instrument concepts (Chen et al., 2002; Chu et al., 2009; Haagen-Schützenhöfer & Hopf, 2014). The use of two-tier multiple-choice tests allows teachers to achieve students' conceptual understanding and also to explore students' reasoning behind these ideas (Tsai & Chou, 2002). Moreover, it facilitates the assessment of misconceptions of a larger sample of students in an effective way in science education research (Voska &Heikkinen, 2000). The summary of studies the advantages and disadvantages of two-tier multiple-choice tests can be seen in Table 2.9.

Table 2.9. Summary of studies two-tier multiple-choice test

No	Two-tier tests in science learning	Studies
	Advantages	
1	Two-tier multiple-choice tests are more readily administered and scored than the other method	Peterson, et al., 1989; Taber, 1999; Tan & Treagust, 1999, Adadan & Savasci, 2012
2	Relatively convenient for students to respond and more practical and valuable for teachers to use in terms of reducing guesswork, allowing for large-scale administration and offering insight students' reasoning	Adadan & Savasci, 2012
3	Two-tier tests provide ease scoring and application	Adadan & Savasci, 2012; Kılıç & Sağlam, 2009.
4	Two-tier tests introduced the degree of error in the description of students' conceptual framework	Griffard &Wandersee, 2001
5	Two-tier tests were considered a great improvement over the previous approaches in that these tests link their choices to misconceptions of the target concept	Wang, 2004
	Disadvantages	
1	Two-tier tests might overestimate or underestimate students' scientific conception	Chang et al., 2007
2	Two-tier tests have some limitations in discriminating lack of knowledge from misconceptions, mistakes, or scientific knowledge	Gurel, Eryilmaz & McDermott, 2015

2.6. Light and optical instrument concepts

Based on the Indonesian Curriculum, the structure of the curriculum consists of an organization of core competencies and basic competencies. The core competency for "Light and Optical Instruments" is understanding (factual, conceptual and procedural) knowledge based on curiosity about science, technology, art, culture-related phenomena, and events that can be seen with our eyes (MoEC, 2013). Basic Competency is formulated to achieve the goal of science learning. Basic competencies for "light and optical instruments" in science subject covered physics and biology that can be seen in Table 2.10.

Table 2.10. Core competency, basic competency and indicator of “light and optical Instruments”

Core Competency	Basic Competency	Indicator of Competency Achievement
Understanding (factual, conceptual and procedural) knowledge based on curiosity about science, technology, art, culture-related phenomena and events that can be seen with our eyes	3.12 Analyzing the properties of light, the formation of images on the plane and curved, and its application to explain the process of vision, and the working principle of optical instruments 4.12 Presenting experimental results on the formation of images on mirrors and lenses	1. Understanding and identifying the properties of light. 2. Understanding and analyzing the formation of images in mirrors and lenses. 3. Understanding and identifying the various optical instruments that students can encounter in everyday life 4. Understanding and investigating the structures and functions of human eyes. 5. Understanding and explaining eye disorders and the solutions for each disorder.

2.6.1. Misconceptions of the properties of light

Analyzing research from previously published documents is very important in order to reveal the student's misconceptions about “Light and Optical Instruments”. The first research work was analyzing the misconceptions of light properties. Light is a complex concept that lends itself to misconceptions among teachers and students (Ling, 2017). The result from previous document studies on light and optical instruments revealed that some of the misconceptions are abundant, regardless of age and academic background. Fetherstonhaugh and Treagust (1992) investigated students’ conceptual understanding of light and its properties, develop materials, and evaluate the effectiveness of a teaching strategy using these materials to elicit conceptual change in the topic. They developed a 16-item diagnostic test in four areas: How does light travel?; How do we see?; How is light reflected?; How do lenses work?. Twelve of the items in the test were in two-tier form with multiple-choice questions accompanied by an open response for the student to provide a reason for choosing the distractor. The diagnostic test identified nine misconceptions and indicated that a large proportion of students had misconceptions before formal instruction. Misconceptions related to how lenses work especially seemed to be strongly held and resistant to change. These nine misconceptions identified in this study are summarized in Table 2.11.

Table 2.11. Misconceptions about light in Fetherstonhaugh and Treagust's (1992)

No	Misconceptions about Light
1.	Light travels a different distance depending upon whether it is day or night.
2.	Light does not travel during the day.
3.	Light does not travel at all during the night.
4.	We see by looking, not by light being reflected to our eyes.
5.	People can just see in the dark.
6.	Cats can see in the dark.
7.	The light stays on mirrors.
8.	Lenses are not necessary to form images.
9.	A whole lens is necessary to form an image.

2.6.2. Misconceptions of the formation of the image on mirrors and lenses

Second analysis is the misconceptions of the formation of the image on mirrors and lenses. A review of the relevant literature on the formation of images has shown various difficulties in dealing with image formation by mirrors and lenses. Because of these difficulties, students tend to develop misconceptions about image formation (Galili et al., 1993). In a study compiled by "Operation Physics," a total of 30 misconceptions were identified that students have developed in learning about light. Misconceptions listed in the "Operation Physics" have also been reported in previous studies (Galili et al., 1991; Osborne et al., 1993). Several misconceptions about image formation by a plane mirror are shown in Table 2.12.

Table 2.12. Misconceptions about the image by a plane mirror

No.	Misconceptions about the image by a plane mirror
1.	If the observer facing a plane mirror moves, the position or size of the object's image in the mirror changes
2.	An image in a plane mirror is on/inside/in front of the mirror
3.	An object's image appears when we look into the mirror. There is no image in the mirror while we are not looking at it
4.	When there is a barrier in front of an object, the image of a part or whole of the object is not formed in the plane mirror
5.	An observer can see the image in the mirror if she or he stands in the same direction as the object; otherwise, she or he cannot see it
6.	The distance of the image in a plane mirror to the mirror itself is greater than the distance of the object to the mirror

Chen et al. (2002) developed a two-tier diagnostic test to identify the misconceptions of Taiwanese high school students about image formation by a plane mirror. They found 9 misconceptions in the study: (1) Students thought that to see an image of any object, it should be inside the front region straight ahead of the mirror. (2) Students thought that image of an object depends on the observer and they believed that image of any object is located right ahead of the observer. (3) Students claimed that image of an object is located on the surface of the mirror, not equal distance behind the mirror as the object is in front. (4) Students thought that if a person wants to see him or herself, he or she should illuminate the mirror rather than himself or herself. (5) Students believed that image of an object is in the line sight of the observer. They could not realize image of an object does not depend on the observer. (6) Students confused the image with the shadow. They expressed image of an object on the mirror was its shadow. (7) Students claimed that image of a black object on the mirror was due to black rays bouncing off the black object. They could not realize that image of the black object was due to the reflection of surroundings around the object and there was no light reflected from the mirror due to the black object. (8) Students confused image formation with shadow formation. They believed that in the presence on an illuminant the position and size of the image of an illuminated object depends on the illuminant. For example, they thought image size of an object gets longer when the illuminant is gotten closer to the object. (9) Finally, students thought position and size of the image of any object depends on the location of the observer. They thought when the observer retreats size and position of the observer is changed.

To understand the nature of an image, we need to understand how light behaves when it reflects from a mirror. A highly polished surface, such as a mirror, reflects most of the light falling on it. The law of reflection is (1) the angle of incidence is equal to the angle of reflection, and (2) the incident ray, the normal to the mirror at the point of incidence and the reflected ray, all lie in the same plane. These laws of reflection are applicable to all types of reflecting surfaces including spherical surfaces. Misconceptions about the law of reflection are: (1) The angle of incidence is the angle between the incident ray and the plane surface of the reflector, while the reflection angle is the angle between the reflected ray and the plane surface reflector; (2) The incident ray and the reflected ray are in a different medium; and (3) The magnitude of the incident ray is not similar to that of the reflected ray (Galili & Hazan, 2000; Saxena, 1991).

Misconceptions about the law of refraction are: (1) The angle of the incident is the angle between the incident ray and the plane surface of medium 1, while the angle of refraction is the angle between the refracted ray with the surface of medium 2; (2) The angle of incident and refracted rays are in medium of the same density; and (3) As the light moves from a less dense medium to a denser medium, the angle of incidence is smaller than the angle of refraction (Fredlund et al., 2012).

In a study of 220 Thai secondary students, students had the significant misconceptions about the direction of propagation of light, how light refracts at an interface and how to determine the position of an image (Kaewkhong et al., 2010). All the misconceptions about image formation by a mirror are based on two fundamental aspects of image formation. The first aspect is the position of the image and its characteristics. The second aspect is the visual field involving the relationship between the observer's position, the position of the object and the position of the image.

2.6.3. Misconceptions of optical instruments, human eye and eye disorders

Optical instruments are the devices which process light wave to enhance an image for more clear view. People use an optical instrument usually to make things bigger and to see fine details of objects with the help of something very simple like a magnifying glass or any complicated device like microscope or telescope. Kutluay (2005) developed a test to diagnose eleventh-grade students' misconceptions about geometrical optics in Turkey. According to the results of the three-tier test, the most prevalent misconceptions which existed in more than 10 % of the sample are listed in Table 2.13. These results were in agreement with the findings of the previous studies (Fetherstonhaugh & Treagust, 1992; Goldberg & McDermott, 1986).

Table 2.13. Misconceptions in optics in the study of Kutluay (2005)

No	Misconceptions in optics	Percentage (%)
1	Eyes can get used to seeing in total darkness.	11
2	Light is emanating in only one direction from each source, like flashlight beams.	18
3	Shadows of the objects are clearer when the bigger bulb is used as a light source.	18
4	Shadow is black color and light is white color. When they overlap, they mix and form the grey color. In a similar way, when the shadow and light overlap, the shadow reduces the brightness of the light.	13
5	An image in a plane mirror lies behind the mirror along the line of sight between a viewer and the object.	14
6	An observer sees the object because the observer directs sight lines toward it, with light possibly emitted from the eyes.	14
7	Image of a black object on the mirror is due to black rays bouncing off the black object.	22
8	While watching an object, its position is also shifted as they view it from different perspectives.	20

2.7. Theoretical framework of the study

Previous studies on improving the conceptual understanding of science suggested that the first step towards an effective teaching and learning process is to identify the misconceptions and use effective teaching strategies to remediate the misconceptions (Çepni et al., 2006; Çibik et al., 2008). To promote meaningful learning, we must develop teaching strategies to eliminate misconceptions. Correcting students' misconceptions depends on not only the delivery of new knowledge but also the gradual integration of new concepts related to students' existing conceptual structures (Vosniadou, 2002). We must develop new instructional methods to support students in constructing and adapting their knowledge (de Jong & Van Joolingen, 1998). The learning theory that supports this method is constructivism.

Constructivism is a theory of learning which believes that learners create or construct new knowledge (Glaserfeld, 1984; Gilakjani et al., 2013). Windschitl and Andre (1998) defined the term constructivism by saying that learners construct their knowledge and conceptions through daily experiences and by reasoning those experiences. Constructivism focuses on "how people learn" or "how people get knowledge". Hence, according to constructivist theory, the learner is an active processor of information and knowledge.

Research on teaching and learning showed that students learn better when they construct their own understanding of scientific ideas within the framework of their existing knowledge (Bransford et al., 2000). To accomplish this process, we must motivate students to engage with the content and must be able to learn from that engagement. Interactive computer simulations can meet both needs. Knowledge is constructed and is influenced by prior knowledge, experiences, and the social aspects of the learning context (Strike & Posner, 1992).

According to constructivism learning theory, students construct their own understanding and knowledge of the world through experiencing things and reflecting on those experiences (Bereiter, 1994). Meaningful understandings occur when students relate new concepts to their existing knowledge that they had learned in the previous lessons (Loyens and Gijbels, 2008; Yager, 1991). This learning is known as student-centered learning (Yager, 1991), which the teacher plays a role as the facilitator of the teaching and learning process. Meaningful science instruction aims to reorganize or replace students' misconceptions as necessary to accommodate scientifically accepted understanding.

Computer simulations offer many attributes that are useful for promoting conceptual understanding and overcome misconceptions. Computer simulations allow students to play a more active role, thus allowing students to construct their own knowledge. This constructivist approach to teaching and learning is important for overcoming misconceptions (Jaakkola, Nurmi, & Veermans, 2011).?

Overcoming students' misconceptions in science have been explored by previous researchers in the science education field. One strategy to overcome misconceptions is using the teaching method. Research related to misconceptions had shown that traditional teaching methods are not effective in overcoming students' misconceptions (Jimoyiannis & Komis, 2001). Overcoming misconceptions requires teaching methods that provide chances for students to reveal their pre-concepts and dissatisfaction with their concepts. Driver et al., (1994) suggested that effective teaching methods must minimize or eliminate the misconceptions that students have. From the previous research on students' misconceptions in science learning, the strategies are most adopted are: using computer simulation (Chen et al., 2013; Moosa, 2015; Ramnarain & Moosa, 2017), using concept cartoon (Yong & Kee, 2017), using constructivist-based approach (Awan, 2013; Ling, 2017), using drawing analysis (Dikmenly, 2010), using inquiry-based learning (Ray & Beardsley, 2008; Heng & Karpudewan, 2017), using cooperative learning approach (Bilgin & Geban, 2006; Manolas & Leal, 2011), using analogy activity (Çalik et al., 2009), and using learning cycle approach in the classroom (Osman, 2017). From these teaching methods, one of the effective methods for overcoming misconceptions is using computer simulation in the classroom (Chen et al., 2013; Ramnarain & Moosa, 2017).

A review from previous research on the effectiveness of computer simulations for supporting science teaching and learning during the past four decades by Smetana and Bell (2012) stated that simulations could help students to eliminate their misconceptions. Bell and Smetana (2008) stated that simulations provide interactive, authentic, and meaningful learning opportunities for students because simulations facilitate the learning of abstract concepts, such as light and optical instruments. This concept is one concept in science learning that difficult for students. A review of the literature about this concept has shown various difficulties in dealing with abstract concepts in the learning process Ling (2017). Because of these difficulties, students tend to develop misconceptions about light and optical instruments. Computer simulations provide a bridge between students' prior knowledge and the learning process of new concepts, also helping students develop scientific understanding through an active reformulation of their misconceptions. Therefore, it is very important to develop computer simulations to overcome students' misconceptions.

To achieve a conceptual understanding of light and optical instrument concepts, the science education literature has suggested various instructional interventions during the learning process that can engender conceptual change resulting in improved conceptual understanding (Chinn & Brewer, 1993). First, the two-tier multiple-choice test was used to identify students' misconceptions about this concept. Second, we used computer simulations as an intervention strategy to overcome and eliminate students' misconceptions. Computer simulations were used to cause dissatisfaction with the students' prior knowledge. The currents study attempts to use computer simulations in applying the constructivist method. The students change traditional science classrooms to constructivist classrooms through adopting a conceptual change model (Posner et al., 1982) in providing the concepts which are thought to be more interesting for students to understand new concepts and attempting to get meaningful learning (not rote learning). Computer simulations have the potentials to achieve the condition of conceptual change suggested by Posner et al., (1982). They use words (as shown on the screen), statics graphics (photos or illustrations) and animations (as dynamic graphics and video) and these make available of the conceptual change condition.

The one unique characteristic of computer simulations is interactivity or the potential for interactivity. Interactivity enables students to manipulate scientific phenomena. It can show the students the impact of this manipulation as immediate feedback. This study focused on interactivity between the student and computer simulations program that will facilitate students being involved in the learning process. Thus, the students will work on constructing scientific knowledge and concepts by examining their previous knowledge or concepts through manipulating scientific phenomena displayed by the program. Figure 2.6 shows a summary of the theoretical framework.

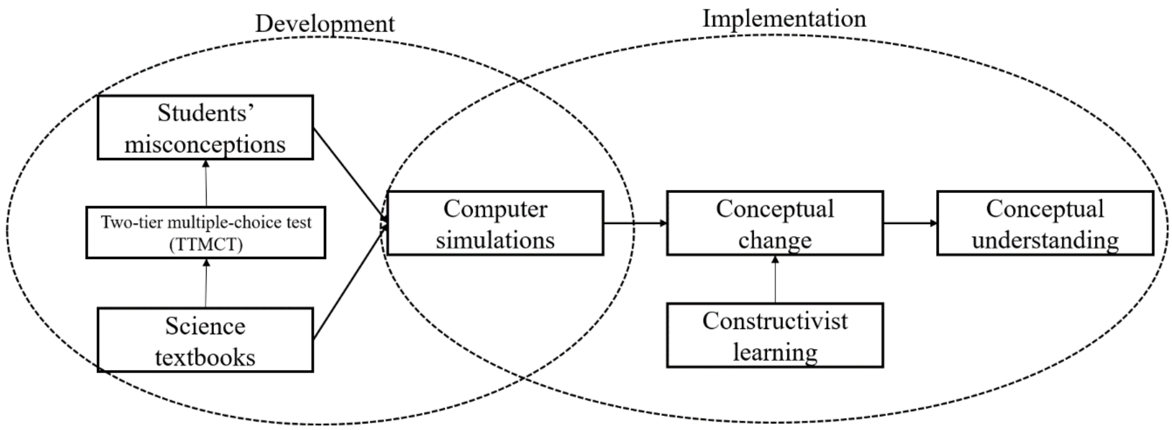


Figure 2.6. Theoretical framework

The background for this study is the demand from the Ministry of Education and Culture (MoEC) of Indonesia for science learning to focus on conceptual understanding through using constructivist teaching. Therefore, the theoretical framework in this study discussing constructivist learning theory and its relationship with computer simulations was designed to improve students' conceptual understanding.

In conclusion, the characteristics of computer simulations may include: First, it can display or introduce a science lesson in a simple and interesting way and being able to display scientific concepts or phenomena in animations and visualizations that facilitate conceptual understanding. Second, it is possible for students to interact with simulations program to manipulate the conditions of the scientific phenomena and to receive immediate feedback. These characteristics may contribute to constructivist learning and changing misconceptions through students to engage in the learning process.

2.8. Summary

Overall, the literature review suggests that computer simulations can be effective learning tools when used as a part of an instructional strategy to help students gain a conceptual understanding in science learning (Chang et al., 2008; Jimoyiannis & Komis, 2001; Jaakkola, Nurmi & Veermans, 2011, Moosa, 2015). Previous research also suggested that using computer simulations in the learning process, students can visualize the abstract concepts and can make abstract science phenomena more accessible and visible to students (Muller, Sharma & Reimann, 2008; Ryoo& Linn, 2012; Stieff, 2011).

The literature review also suggests that computer simulations play an important role in the science classroom and science instruction. Computer simulations give an opportunity for students to observe real-world experience and interact with it. Through simulations, learners can get an understanding of difficult to grasp concepts in science learning.

Using computer simulations in the classroom have a positive finding on conceptual understanding (Ramasundarm, et al., 2005; Abdullah & Syarif, 2008; Plass et al., 2012; Nowak et al., 2013; Sarabando et al., 2014). Using computer simulations also helps the students to understand difficult science concepts (Plass et al., 2012; Webb, 2012; Sarabando et al., 2014).

CHAPTER 3
METHODOLOGY

3.1. Overview of the chapter

The methodology and the overall research design of the present study are described in this chapter. This chapter contains information about research design, the sample of the study, research instruments, teaching intervention, and method of data analysis. This chapter also presents the research methods used for the pilot study and the main study.

3.2. Overall research design

The overall research designs of this study are shown in Figure 3.1. This chapter provides a complete description of the steps that were undertaken to achieve the general aimof the study. The general aim of this study was to investigate the effectiveness of computer simulations to improve Indonesian junior high school students' conceptual understanding and overcome their misconceptions about light and optical instrument concepts. To achieve the research aim in the current study, there were three main studies of the whole research procedure.

The first stage was developing TTMCT about the concept of "light and optical instruments" for 8thgrade to assess students' conceptual understanding and identified students' misconceptions. The data used in this study were science textbooks and expert's questionnaire. This stage also involved the pilot study of the TTMCT and some qualitative interviews regarding the questionnaire. The aim of the pilot study was to test the effectiveness of the TTMCT regarding content coverage and language appropriateness. The methods used of this stage were three stages using the procedure by Treagust (1988, 1995). The analysis construct validity, content validity, and item test analysis were used to analyze TTMCT. Analysis of response combinations from the administration of TTMCT was used to investigate students' misconceptions of light and optical instruments. Results from this stage were: (1) a valid and reliable TTMCT and (2) twenty-two misconceptions about light and optical instruments. The result of this stage was used as inputs in the next stages.

The second stage was developing computer simulations of light and optical instrument concepts to improve students' conceptual understanding and overcome students' misconceptions. The data used in this study were twenty-two students' misconceptions of light and optical instruments and teacher's questionnaire. The methods used in this stage were the 4-D model: define, design, develop, and disseminate. The computer simulations were developed using software Adobe Flash Professional CS6. The computer simulations in this research were developed based on the students' misconceptions that were found in the first stage using TTMCT. The development process of computer simulations also considered the contents of light and optical instrument concepts by adjusting the content of the computer simulations and the structure of the science curriculum in Indonesia. Six science teachers reviewed the computer simulations program to gain comments and suggestions for further improvement using a set of a questionnaire which comprises 10 item questions with a 5-point Likert scale. Results from this stage were computer simulations of light and optical instruments. The result of this stage was used as inputs in the next stages.

The third stage was implementing computer simulations in response to research questions 4, which aims to improve students' conceptual understanding and overcoming students' misconceptions about light and optical instrument concepts using computer simulations. This stage used TTMCT and computer simulations of light and optical instrument concepts. This stage used a quasi-experimental design involving experimental and control groups. For the experimental group, the learning process of light and optical instrument concepts was taught using computer simulations, and for the control group, the same concept was taught using science textbooks.

The test score was analyzed quantitatively. For each of the TTMCT items, the first tier comprised one correct answer, and the second tier involved selecting the best reason for the response in the first tier. If a student answered the first tier and second tier (combined tiers) correctly, a maximum of 75 points is possible. Students' responses were analyzed to define their understanding. For this purpose, correct answers were converted to percentages. The total score for each student was calculated and tabulated for statistical analysis using the IBM Statistical Package for Social Science version 22 to analyzed independent t-test and ANCOVA.

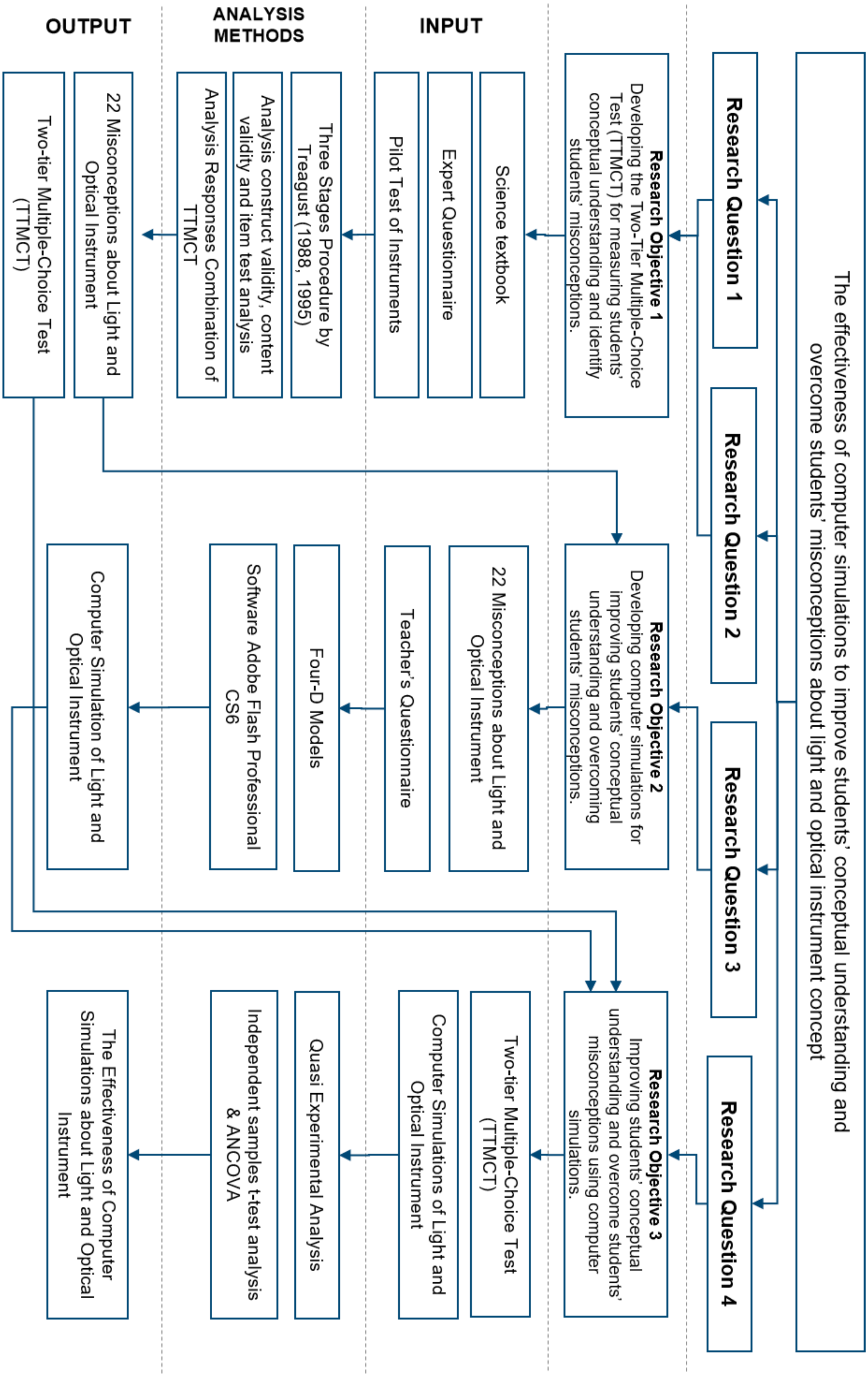


Figure 3.1. The overall research designs of this study

3.3. Sample of study

3.3.1. Participating students

The population of this research comprised junior high school students in 8th grade and science teachers. The sample of this study was 264 junior high school students in 8th grade from three public schools in Semarang city, Central Java, Indonesia. Purposive random sampling was used to determine this sample. The purposive sampling technique is a non-probability sampling that is most effective when one needs to study a certain cultural domain with a specific knowledge or skill (Gentles et al., 2015).

For this study, we divided the sample into two groups, the experimental and a control group. The students have a similar background. The average age of students was 13.5 years old (ranging from 13 to 14 years old). An expert teacher taught the students light and optical instrument concepts. The researcher and the teachers discussed the proper ways of using computer simulations in the classroom. The distribution of the students' sample according to gender is summarized in Table 3.1.

Table 3.1. Distribution of students' group sample

		Sex		Total
		Male	**Female**	
Group	Experimental	40 (30.8%)	90 (69.2%)	130 (100%)
	Control	49 (36.6%)	85 (63.4%)	134 (100%)
Total		**89 (33.7%)**	**175 (66.3%)**	**264 (100%)**

3.3.2. Participating teachers

Four teachers volunteered to take part in the study as shown in Table 3.2. All the teachers are experienced over twenty years in the science teaching field. They are also an expert in the teaching of light and optical instrument concepts. The researcher and the teachers have discussed the teaching material before we conducted the lessons. We also discussed the proper ways of using computer simulations in the classroom. The teachers' role was a facilitator during the lesson and doing an activity using computer simulations.

Table 3.2. Science teacher participants

No	Teacher code	Age	Academic background	Experience
1.	BA	50 years old	Bachelor in science education	28 years
2.	MD	58 years old	Bachelor in science education	32 years
3.	SS	58 years old	Bachelor in science education	36 years
4.	TI	45 years old	Bachelor in physics education	21 years

3.4. Data collection instrument

This study used two-tier multiple-choice tests (TTMCT) and computer simulations of light and optical instrument concepts. The details of the instruments used are described below.

3.4.1. Two-Tier Multiple-Choice Tests (TTMCT)

Two-Tier multiple-choice tests (TTMCT) were developed by authors. The TTMCT included 25 question items used to identify misconceptions and to test students' conceptual understanding of light and optical instruments. Items in the TTMCT required understanding in five key conceptual categories relating to light and optical instruments. In the Indonesian curriculum, the topic of light and optical instruments covers the properties of light, the formation of images in mirrors and lenses, optical instruments, the structure and function of human eyes, and eye disorders and the solutions for each disorder (MoEC, 2017). The example of questions in the TTMCT about light and optical instruments in this study is shown in Figure 3.2.

1. What is the definition of light?
   A. Light is an electromagnetic wave
   B. Light is a mechanical wave
   C. Light travels an unlimited distance
   D. Light is a longitudinal wave

   Reason:
   a. Light has an infinite speed
   b. Light can travel through a vacuum
   c. Light can pass through all object
   d. Light can propagate if there is a medium
2. We can see the fish in the aquarium. The fact about the relationship between light and the ability of the eye to see objects is...
   A. The eye can see objects because the object can absorb the received light
   B. The eye can see objects because the objects reflected light, so that light enters the eye
   C. The eye can see objects because the object refracted light, so that light enters the eye
   D. The eye can see objects because the eye nerves can see objects, so the ability of the eye to see the object has no relationship with light

   Reason:
   a. Eyes can see even without light
   b. Eyes can produce light, so the eyes can see objects
   c. The light coming from a light source directly enters our eyes
   d. If there is no light to reflect at an object, no object can be seen

Figure 3.2. Examples of questions in the TTMCT

The literature shows that there are various advantages of using two-tier multiple-choice tests and this model has been used extensively in misconceptions studies (Treagust 1988, 1995). A two-tier diagnostic test, as Treagust (1988) reported, was first developed with items specifically designed to identify alternative conceptions and misunderstandings in clearly defined content areas of science. Since that time, some two-tier tests have been developed and reported in the literature (Treagust & Chandrasegaran, 2007). Two-tier diagnostic tests have been regarded as an effective assessment tool to determine students' conceptual understanding (Treagust, 1988; Odom & Barrow, 1995; Lin, 2004; Sesli & Kara, 2012; Adadan & Savasci, 2012).

In a two-tier test, the first tier asked the student to choose about the content in some specific concept; and the second tier asked the student about the reason or explanation for choice in the first tier. The reasons comprise the designated correct answer, together with identified students' conceptions or misconceptions. The reasons were from students' responses given to each open response questions as well as information gathered from the interviews and the literature. In Treagust's (1988) method for the scoring of two-tier items, each item was correctly answered if a student's choice of the first tier (the concept of light and optical instruments) and the second tier (the reason for the first tier) were both correct. With this stringent method of scoring, the chances of getting a correct answer by guessing were very low.

3.4.2. Computer simulations of light and optical instruments

The computer simulations on light and optical instrument concepts contain several parts, such as the opening page, competency, material, and evaluation. The opening page shows to users that the computer simulations were developed to overcome students' misconceptions in light and optical instrument concepts.

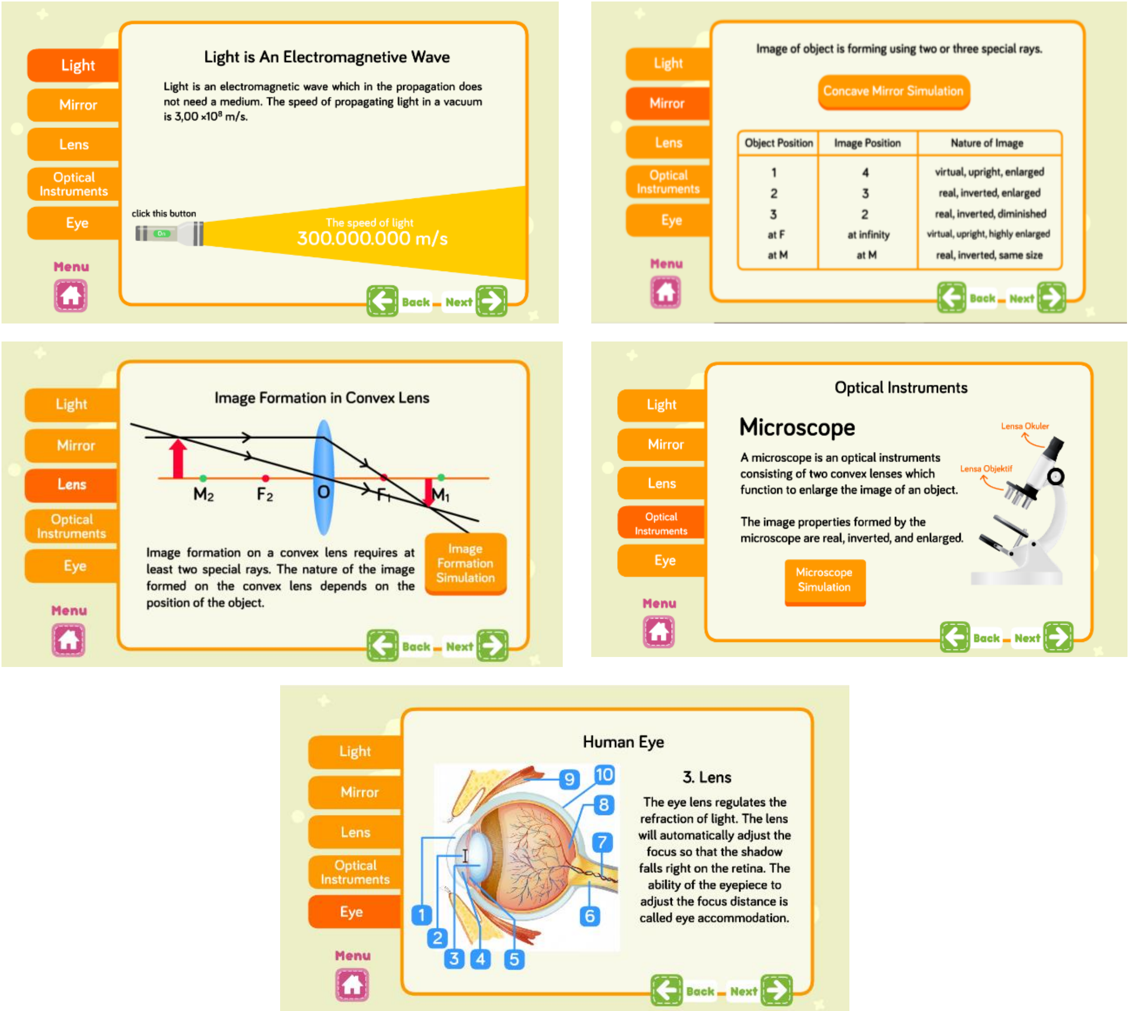


Figure 3.3. Computer simulations program of light and optical instrument concepts

The competency part shows the core competency, basic competency, and an indicator of competency achievement. The material part is the main part of the computer simulations. In this part, the concepts of light and optical instruments are divided into five material topics, (1) light, (2) mirror, (3) lens, (4) optical instruments, and (5) Eye. The material part contains summaries and additional materials that students can use to complete the science learning about light and optical instrument concepts. The materials are also equipped with simulations that can facilitate students to overcome students' misconceptions and understand the concept of light and optical instruments. For instance, the simulation of light is an electromagnetic wave, image formation in a concave mirror, image formation in a convex lens, microscope and the human eye are shown in Figure 3.3.

3.5. Pilot study

To validate the TTMCT, a pilot study was conducted. For the pilot study, 95 junior high school students were involved. These students had completed a unit on light and optical instruments. The main goal of the pilot study was to test the effectiveness of the TTMCT regarding content coverage and language appropriateness. From the pilot test, we identified that students needed about 80 minutes to complete the TTMCT.

3.6. Teaching intervention

The usual science teacher taught both the experimental and control group the lesson about light and optical instrument concepts. Both groups were instructed for an equal amount of instructional time. Five lessons were used to teach the concept of light and optical instruments. After the first lesson, students should be able to understand and identify the properties of light. After the second lesson, students should be able to understand and analyze the formation of an image in mirrors and lenses. After the third lesson, students should be able to understand and identify optical instruments. After the fourth lesson, students should be able to understand and investigate the structures and functions of human eyes. After the fifth lesson, students should be able to understand and explain eye disorders and the solutions for each disorder. The teacher plays the role of a facilitator. Both the control and experiment groups experienced the same teaching and learning process but using different teaching and learning methods. The learning process of light and optical instrument concepts can be seen in Figure 3.4.

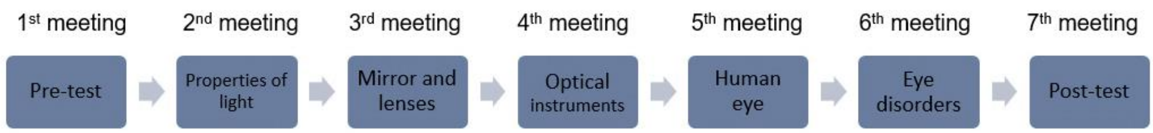


Figure 3.4 Learning process of light and optical instrument concepts

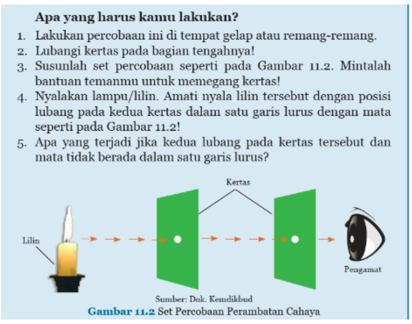
3.6.1. Control group instruction

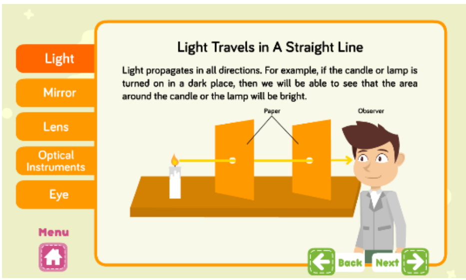
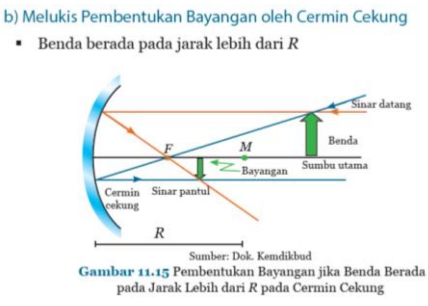
In the control group, the teacher implemented a scientific approach called with the 5M approach to teach light and optical instrument concepts. The learning process of this approach comprises five main learning experiences: observing (*mengamati*), questioning (*menanya*), experimenting (*mencoba*), associating (*menalar*), and communicating (*mengkomunikasikan*). During the lessons, the teacher explained to the students of light and optical instrument concepts. Students used the textbooks provided by the Ministry of Culture and Education (MoEC).

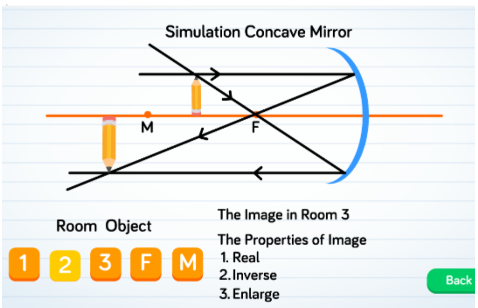
3.6.2. Experimental group instruction

The teacher instructed the experimental group using a 5M approach and computer simulations in the learning process of light and optical instrument concepts. During the lessons, the teacher presented computer simulations of light and optical instrument concepts to the students. After completing the lesson, the teacher guided the students to make conclusions. Detailed treatment and procedures in the control and experimental group are shown Table 3.3.

Table 3.3. Detailed instructions and procedures in the control and experimental group

<table>
<tr><th>Duration (minutes)</th><th>Control group</th><th>Experimental group</th></tr>
<tr><td>1st meeting (80 minutes)</td><td>pre-test of conceptual understanding using a two-tier multiple-choice test.</td><td>pre-test of conceptual understanding using a two-tier multiple-choice test.</td></tr>
<tr><td>2nd meeting (80 minutes)</td><td>The teacher implements 5M activity to teach the properties of light.
The teacher and student used textbooks to discuss and make a conclusion about the properties of light.


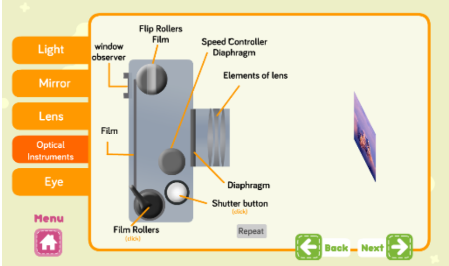
Gambar 11.2 Set Percobaan Perambatan Cahaya</td><td>The teacher implements 5M activity to teach the properties of light.
The teacher and student used computer simulations to discuss and make a conclusion about the properties of light.

</td></tr>
<tr><td>3rd meeting (80 minutes)</td><td>The teacher implements 5M activity to teach mirrors and lenses.
The teacher and student used textbooks to discuss and make a conclusion about mirrors and lenses.


Gambar 11.15 Pembentukan Bayangan jika Benda Berada pada Jarak Lebih dari R pada Cermin Cekung</td><td>The teacher implements 5M activity to teach mirrors and lenses.
The teacher and student used computer simulations to discuss and make a conclusion about mirrors and lenses

</td></tr>
<tr><td>4th meeting (80 minutes)</td><td>The teacher implements 5M activity to teach optical instruments.
The teacher and student used textbooks to discuss and make a conclusion about optical instruments.</td><td>The teacher implements 5M activity to teach optical instruments.
The teacher and student used computer simulations to discuss and make a conclusion about optical instruments.</td></tr>
</table>

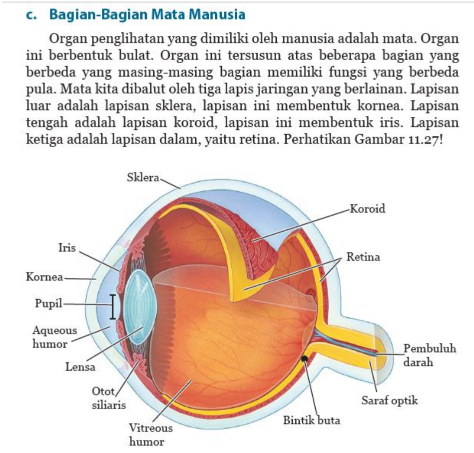
Duration (minutes)	Control group	Experimental group

nyata, terbalik, dan lebih kecil dari benda aslinya. Perhatikan prinsip kerja kamera sederhana ini dengan diagram cahaya lensa cembung. Ukuran bayangan tersebut bergantung pada panjang fokus lensa, dan jarak lensa itu pada film tersebut. Jika diperhatikan, bagian-bagian dari kamera memiliki kemiripan dengan mata. Cobalah mengidentifikasi bagian-bagian kamera yang memiliki fungsi yang serupa dengan bagian-bagian mata!

Sumber: (a) Haliday & Reisnick, (b) Dok. Kemdikbud
Gambar 11.36 Pembentukan Bayangan pada Kamera Analog

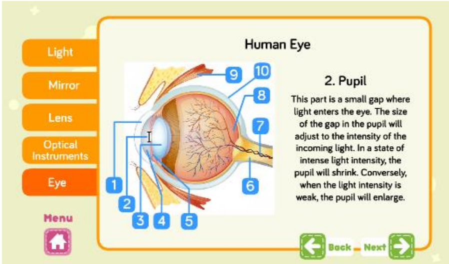


Duration (minutes)	Control group	Experimental group
5th meeting (80 minutes)	The teacher implements 5M activity to teach the human eye. The teacher and student used textbooks to discuss and make a conclusion about the human eye.	The teacher implements 5M activity to teach the human eye. The teacher and student used computer simulations to discuss and make a conclusion about the human eye.

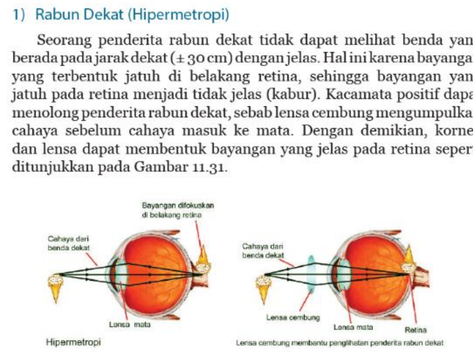


c. Bagian-Bagian Mata Manusia

Organ penglihatan yang dimiliki oleh manusia adalah mata. Organ ini berbentuk bulat. Organ ini tersusun atas beberapa bagian yang berbeda yang masing-masing bagian memiliki fungsi yang berbeda pula. Mata kita dibalut oleh tiga lapis jaringan yang berlainan. Lapisan luar adalah lapisan sklera, lapisan ini membentuk kornea. Lapisan tengah adalah lapisan koroid, lapisan ini membentuk iris. Lapisan ketiga adalah lapisan dalam, yaitu retina. Perhatikan Gambar 11.27!

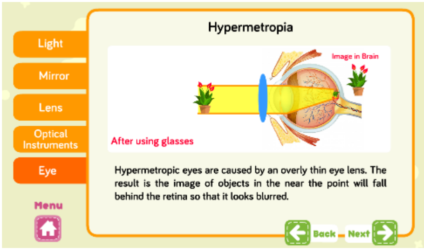


Duration (minutes)	Control group	Experimental group
6th meeting (80 minutes)	The teacher implements 5M activity to teach eye disorders. The teacher and student used textbooks to discuss and make a conclusion about eye disorders.	The teacher implements 5M activity to teach eye disorders. The teacher and student used computer simulations to discuss and make a conclusion about eye disorders.



1) Rabun Dekat (Hipermetropi)

Seorang penderita rabun dekat tidak dapat melihat benda yan berada pada jarak dekat (± 30 cm) dengan jelas. Hal ini karena bayanga yang terbentuk jatuh di belakang retina, sehingga bayangan yan jatuh pada retina menjadi tidak jelas (kabur). Kacamata positif dapa menolong penderita rabun dekat, sebab lensa cembung mengumpulka cahaya sebelum cahaya masuk ke mata. Dengan demikian, korne dan lensa dapat membentuk bayangan yang jelas pada retina seper ditunjukkan pada Gambar 11.31.



Duration (minutes)	Control group	Experimental group
7th meeting (80 minutes)	post-test of conceptual understanding using a two-tier multiple-choice test.	post-test of conceptual understanding using a two-tier multiple-choice test.

Note: The researcher was present throughout the treatment and data collection process.

3.7. Data analysis

The test score was analyzed quantitatively. For each of the two-tier test items, the first tier comprised one correct answer and the second tier consisted involved selecting the best reason for the response in the first tier. The total score for each student was calculated in percentage, tabulated and processed in a computer for statistical analysis using the IBM Statistical Package for Social Science version 22. To analyze the test items, two criteria were used to classify and to mark the students' reasons. Two-tier multiple-choice test items were analyzed with the criteria presented in Table 3.4. These criteria are the same used by Coştu et al. (2007), Özmen et al. (2009) and Abdullah et al. (2017) to analyze the two-tier test items. Correct category if the student answered the content and reason tier correctly. Partial correct category if the student answered the content question correctly but provided an incorrect reason or, the student answered content incorrectly but provide a correct reason. Incorrect category if the student answered both tiers incorrectly.

Table 3.4. Criteria for analyzing the TTMCT

First tier	Second tier	Abbreviations	Categories	Score
Correct Answer	Correct Reason	CC	Correct	3
Wrong Answer	Correct Reason	WC		2
Correct Answer	Blank	CB	Partially correct	2
Correct Answer	Wrong Reason	CW		1
Wrong Answer	Blank	WB		0
Wrong Answer	Wrong Reason	WW	Incorrect	0
Blank	Blank	BB		0

We administered the final form of the TTMCT to the students before instruction (pre-test) and after instruction (post-test). We analyzed student responses to define their categories based on pre-test and post-test responses. For this purpose, we converted correct responses to percentages. An independent samples t-test analysis was performed for the data obtained from the TTMCT to assess the differences between the experimental and control group. For both groups, students' correct responses of pre-test and post-test to the first tier and the combined tiers to each of the 25 items were analyzed. In addition, the percentage of students holding misconceptions from two groups in the pre-test and post-test were identified.

3.8. Ethical considerations

All the research projects should follow ethical considerations when the research involves human participation (Alshenqeeti, 2014) Therefore, the researcher informed the participants (students and teachers) the aim of the study about investigating the effect of computer simulations on students' conceptual understanding. The participants were informed about the detail information of the research, its potential risks, its benefits, and whom to contact if they had questions. The researcher also applied for ethical permission to the board of education office of Semarang City. The education office granted permission to conduct research in public schools and we can find this letter in Appendix 3. Permission was given to conduct research in SMP 6 Semarang, SMP 7 Semarang, and SMP 41 Semarang.

3.9. Summary

In this chapter, the research design, the method, and the participants in this study were explained. The teaching intervention used in the control and experimental group were also discussed. This chapter also outlined the ethical procedures followed in this research.

CHAPTER 4
DEVELOPMENT OF TWO-TIER MULTIPLE-CHOICE TEST TO ASSESS STUDENTS' CONCEPTUAL UNDERSTANDING ABOUT LIGHT AND OPTICAL INSTRUMENTS

4.1. Overview of the chapter

This chapter discusses the development of the Two-Tier Multiple-Choice Test (TTMCT) in response research questions 1 which aims to develop TTMCT to measure students' conceptual understanding about light and optical instruments and research questions 2 which seeks to identify the students' misconceptions for junior high school students about light and optical instrument concepts. The first stage of this study was developing TTMCT. A TTMCT about the concept of "light and optical instruments" was developed by the author. The test development procedure had three general steps: defining the content area of the test, identification of students' conceptions, and the development of the test. The final version of TTMCT comprised 25 question items. To validate the TTMCT, we conducted a pilot study. The pilot study involved 95 junior high school students. These students had completed a unit about light and optical instruments. The main goal of the pilot study was to test the effectiveness of the TTMCT regarding content coverage and language appropriateness. From the pilot test, it was identified that students needed about 80 minutes to complete the TTMCT. Two experienced science teachers and three science lecturers validated the content of the questions in the TTMCT. We provided the validator with a description of tasks and the concept outline to test the validity of the instruments. The validator commented that (1) the content of the instruments covered almost 95% of the syllabus and suitable to be used, (2) the language used was understood by the students, (3) the reliability of the TTMCT was 0.76 showing that the instrument has high reliability. Based on the data analysis, twenty-two misconceptions were identified. The results of the study showed that the TTMCT was effective to determine the students' misconceptions of light and optical instrument concepts.

4.2. Introduction

Conceptual understanding in science learning has been the main concern of the researchers in the science education field. Students' conceptual understanding cannot be measured or observed. Teachers need to probe students' understanding before and after instruction. To measure students' conceptual understanding of several concepts in a science subject, different diagnostic tools have been developed and used. Among them, interviews, open-ended tests, and multiple-choice tests are found to be the ones commonly used in science education research (Gurel et al., 2015).

Multiple-choice tests have been used for measuring students' understanding of concepts as they enable a large number of students to be sampled in a given amount of time as compared to time-consuming interviews. These tests are also easy to administer and score, and the results obtained are also easily processed and analyzed (Peterson, Treagust, & Garnett, 1989; Taber, 1999; Tan & Treagust, 1999). However, multiple-choice questions may not always show students' understanding or detect students' misunderstanding for a particular concept (Griffard & Wandersee, 2001). The use of a two-tier diagnostic test (Treagust, 1988) has provided a better way to improve how students' conceptions can be evaluated.

A two-tier diagnostic test was first developed with items designed to identify alternative conceptions and misunderstandings in defined content areas of science. Since that time, several two-tier tests have been developed and reported in the literature (Treagust & Chandrasegaran, 2007). Two-tier diagnostic tests have been regarded as an effective assessment tool to determine students' conceptual understanding (Treagust, 1988; Odom & Barrow, 1995; Chen et al., 2002; Lin, 2004; Cengiz, 2009; Sesli & Kara, 2012; Adadan & Savasci, 2012).

One factor that affects students' conceptual understanding is misconceptions. Misconceptions have occurred if the students' understanding of a concept differs from the scientific concept (Nakhleh, 1992). Misconceptions are stable cognitive structures to change, affect students' conceptual understanding, and must be overcome so that students learn scientific concepts effectively (Hammer, 1996). Misconceptions have become a part of the science education area. Previous researchers have done lots of studies to investigate the students' misconceptions, particularly in light and optical instrument concepts.

Light and optical instruments are important science concepts included in the curriculum of many countries (Jones & Zollman, 2014). Although everyday experience with light and optical instrument concepts, understanding of this concept turn out to be difficult for students. According to Ling (2017), light is a complex concept in science learning. Because of the complexity of the concept and difficulty of the subject, students have various misunderstandings and hence have developed misconceptions about light and optical instrument concepts. According to the national curriculum in Indonesia, light and optical instrument concepts are taught at the 8th-grade student in junior high school (MoEC, 2017). This concept is expanded and taught in the upper grade in senior high school. If the students' misconceptions about light and optical instrument concepts are not corrected, students will carry these misconceptions to the upper grades. Dealing with this issue, the development of a two-tier multiple-choice test for testing students' conceptual understanding of light and optical instruments may lead to more meaningful learning. Therefore, the aim of this study was to develop a two-tier multiple-choice test to assess students' conceptual understanding and to explore students' misconceptions about light and optical instrument concepts.

4.3. Method for developing TTMCT

This study used a mixed method by incorporating both qualitative and quantitative methods. The TTMCT was developed in three stages using the procedure by Treagust (1988, 1995). We divided the procedure into three stages as shown in Figure 4.1. Stage 1 was defining the content area of the study. Stage 2 was the identification of students' conceptions from previous literature and students' responses. Stage 3 was several steps in the designing of the test items and the validation of the final version of the TTMCT.

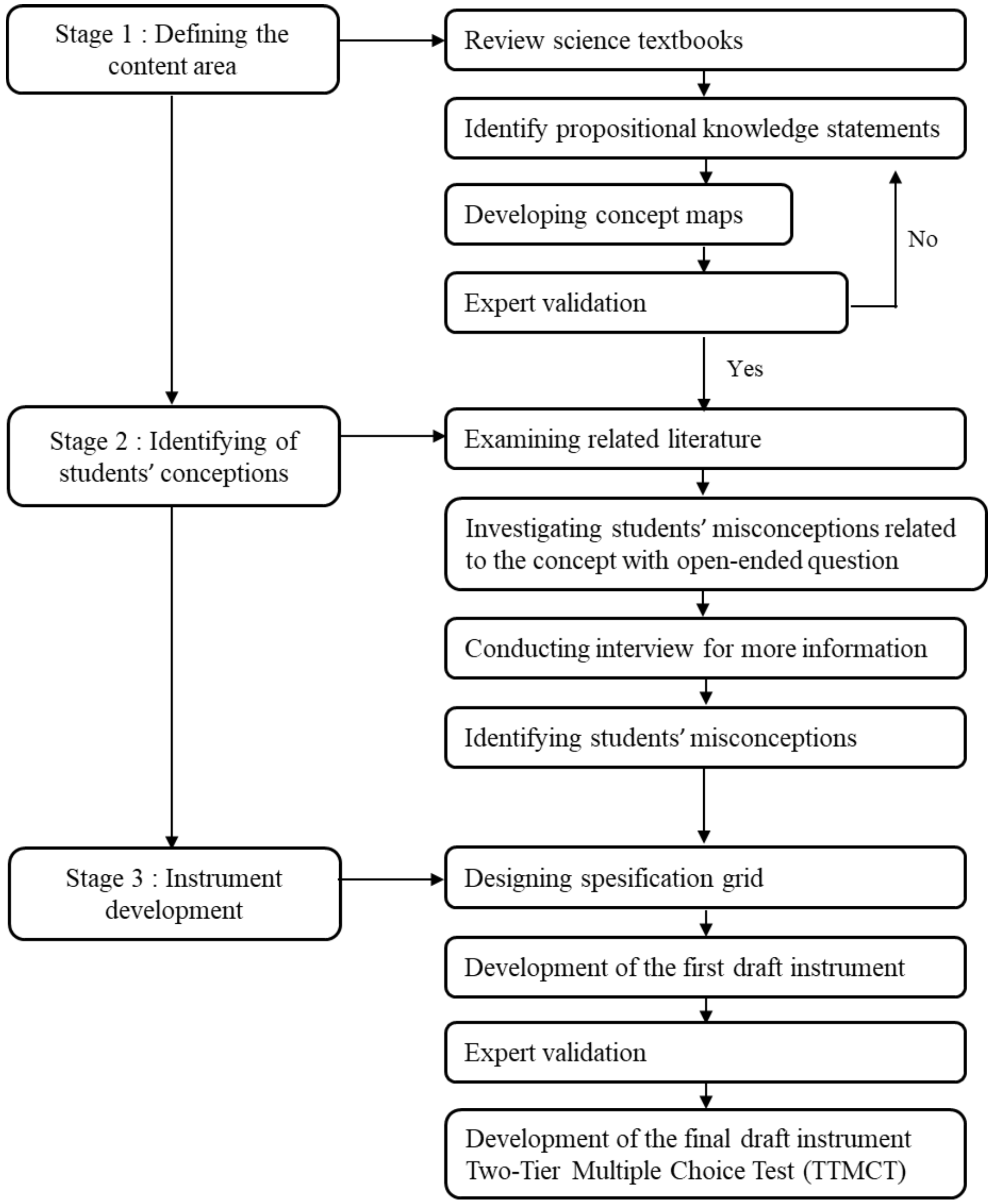


Figure 4.1. The flowchart of instrument development based on Treagust (1988,1955)

4.3.1. First stage: Defining the content area

The first stage was defining the content area. Based on the science textbooks in Indonesia, the content area of light and optical instrument concepts was identified. The content area defined into five concept boundaries mentioned in the indicator of competency achievement. They are the properties of light, the formation of images in mirrors, the formation of images in lenses, optical instruments, and the human eye and eye disorders. The distribution of the content area of light and optical instrument concepts in the TTMCT based on science textbooks shows in Table 4.1.

Table 4.1. The content area of light and optical instrument concepts in the TTMCT

Basic Competency	Indicator of competency achievement	Number of questions
3.12 Analyzing the properties of light, the formation of images in the plane and curved surfaces, and its application to explain the process of vision, and the working principle of optical instruments 4.12 Presenting experimental results on the formation of images in mirrors and lenses	1. Understanding and identifying the properties of light.	Q1, Q2, Q3, Q4, Q5
	2. Understanding and analyzing the formation of images in mirrors and lenses.	Q6, Q7, Q8, Q9, Q12, Q13
	3. Understanding and identifying the various optical instruments that can be found in everyday life	Q18, Q20, Q21, Q22
	4. Understanding and investigating the structures and functions of human eyes.	Q10, Q11, Q19, Q23, Q24
	5. Understanding and explaining eye disorders and the solutions for each disorder.	Q14, Q15, Q16, Q17, Q25

The content area of light and optical instruments was encapsulated into concept maps. Then, the relationship between the concept maps was checked. The concept map of light and instruments can be seen in Figure 4.2. Concept maps have helped represent the qualitative aspects of scientific phenomena (Novak & Gowin, 1984). A concept map aims to show what key terms are involved in making up the content of a phenomenon and how these terms are linked to each other in a hierarchical and integrated manner. Concepts are not isolated bits. Statements about the relationships between the key concepts in a concept map will form a propositional statement. In this study, the propositional statements represent knowledge required to comprehend the relationships among light, mirror, lens, eye, and optical instruments. The propositional statements extracted from the concept maps are:

(1) The properties of light are light travel in a straight line, light can be reflected, light can be refracted, light is an electromagnet wave, light can be dispersed.
(2) There are three types of mirrors: plane mirror, concave mirror, and convex mirror.
(3) There are two types of lenses: convex lens and concave lens.
(4) Snell's law applies to the reflection and refraction of light.
(5) Optical instruments consist of magnifier, telescope, microscope, camera, and eye.
(6) Parts of the human eye are cornea, pupil, eye lens, aqueous humor, optical nerve, sclera, and retina.
(7) There are three kinds of eye disorders: myopia, hypermetropia, and presbyopia.

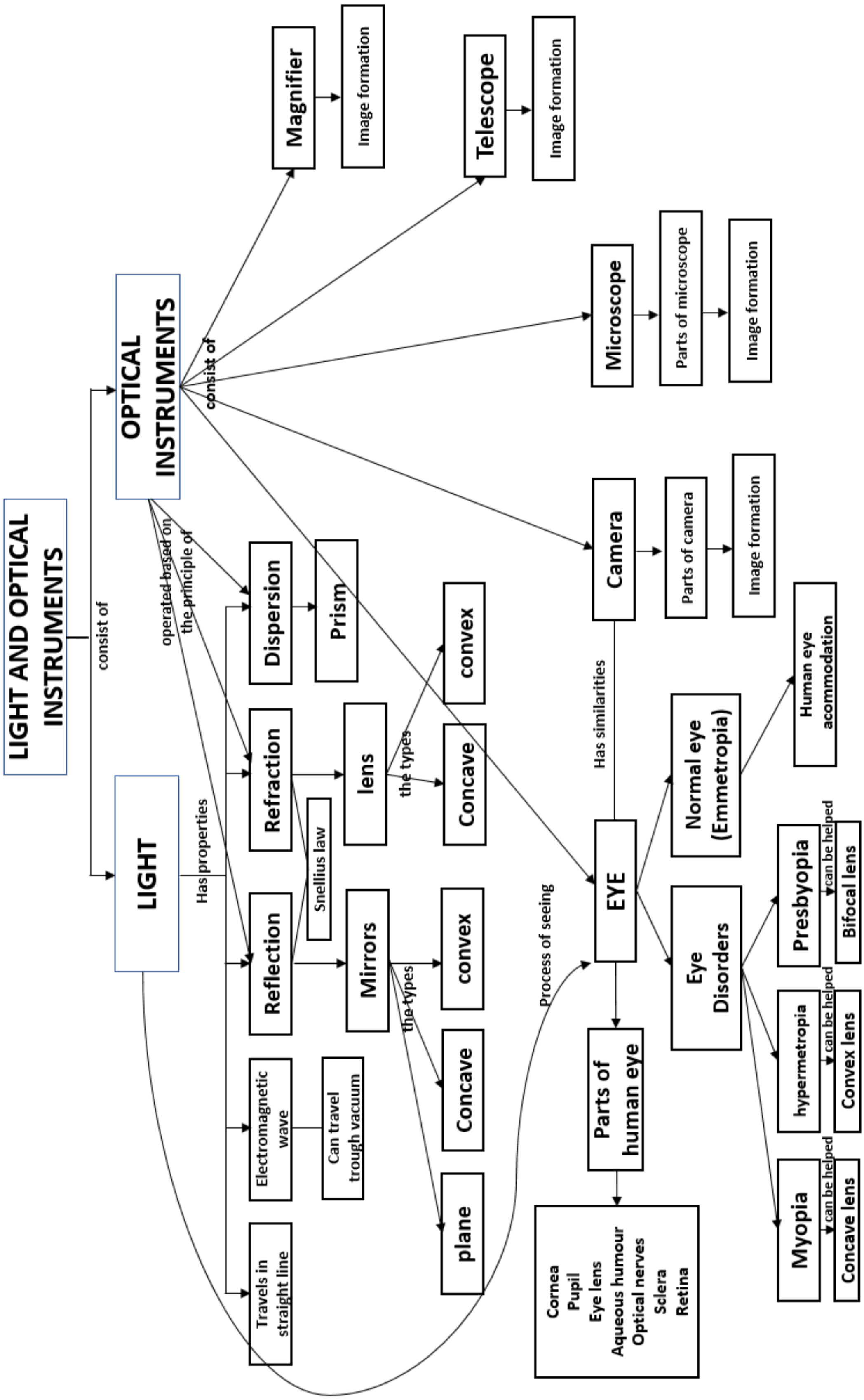


Figure 4.2. Concept map of light and optical instruments

4.3.2. Second stage: Identification of students' conceptions

The second stage was the identification of students' conceptions. This stage emphasized the identifying of students' conceptions. Students described and explained the light and optical instrument concepts using multiple levels of representations. Students' conceptions were identified using free-response questions that comprise 13 questions related to light and optical instrument concepts (Figure 4.3). We administered these questions to 40 students in grade 8th junior high school, who are chosen by using purposive random sampling. For more information and a deeper perspective of students' conceptions, semi-structured interviews were conducted. The interviews continued 20 to 30 minutes. Students' conceptions were identified by the structured protocols.

1. What do you know about light?
2. What are the properties of light?
3. What are the relationships between light and wave?
4. What do you know about mirrors?
5. Explain about types of the mirror and its function?
6. What do you know about lenses?
7. Explain about types of lens and its function?
8. What do you know about optical instruments?
9. Explain about types of optical instruments and their function?
10. Explain about parts of the human eye? What is the function of each part?
11. Explain the process of how the human eye can see objects?
12. What kind of eye disorders do you know? How is the solution for each eye disorders?
13. Draw a concept maps about light and optical instruments?

Figure 4.3. Questions for identifying students' conceptions

4.3.3. Third stage: Development of TTMCT

The third stage was the development of TTMCT. This stage focused on the design of TTMCT. The first stage and second stage were used to develop the first draft of the TTMCT. Based on the specification grid, 25 items TTMCT were developed. Each item of the instrument comprises two sections. In a TTMCT, the first tier asks a student to choose about some specific concept related to light and optical instrument concepts; and the second tier asks the student about the reason or explanation for choice in the first tier. There are four choices for both tiers. Treagust (1985) described that the first tier of each item in the test related to proportional statements and parts of the concept map. Three science lecturers and two science teachers who had experience in the concept of light and optical instruments validated the instrument of the first version. After that, we revised the instruments based on the suggestions and comments from experts. Then, the final version of TTMCT was developed and comprised of 25 items question.

The TTMCT comprises 25 item questions related to the concept of light and optical instruments. Items 1, 2, 3, 4, and 5 concerned with the properties of light. The formation of images in mirrors and lenses represented in items 6, 7, 8, 9, 12, and 13. Item 18, 20, 21, and 22 involved the concept of optical instruments. The concept of the human eye was showed in items 10, 11, 19, 23, and 24. The concept of eye disorders was available in item 14, 15,16, 17, and 25. Details indicator of questions in TTMCT can be seen in Table 4.2.

Table 4.2. Indicator of questions in TTMCT

Topic	Indicator of question	Item
The properties of light	Definition of light	Q1
	The relationship between light and vision	Q2
	Monochromatic and polychromatic light	Q3
	Light refraction	Q4
	Light as a transversal wave	Q5
The formation of an image in mirrors and lenses	Image formation in a plane mirror	Q6
	The law of reflection	Q7
	The relation between an incident and reflection ray	Q8
	Image formation between two plane mirrors	Q9
	Image formation in a concave mirror	Q12
	Analyzing the focus of the concave mirror	Q13
Optical instruments	The image formation in the convex lens	Q18
	The parts of the microscope	Q20
	The image formation of eye and camera	Q21
	Similarities of human eye and camera	Q22
Human eye	Part of the human eye (retina)	Q10
	Part of the human eye (eye lens)	Q11
	Definition of human eye accommodation	Q19
	The relationship between presbyopia and eye lens	Q23
	Part of the human eye (aqueous humor)	Q24
Eye disorders	Eye disorders (myopia)	Q14
	The eyeglasses for myopia	Q15
	Eye disorders (hypermetropia)	Q16
	The characteristic of nearsighted eyes	Q17
	The solution for myopia	Q25

4.3.3.1. Expert validation

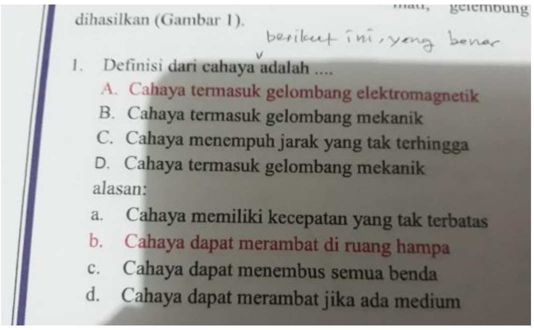
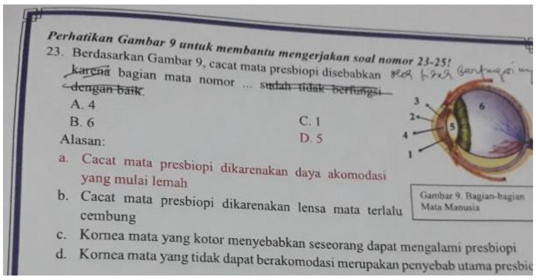
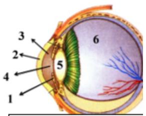
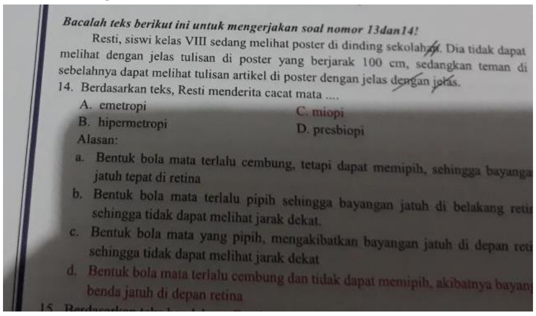
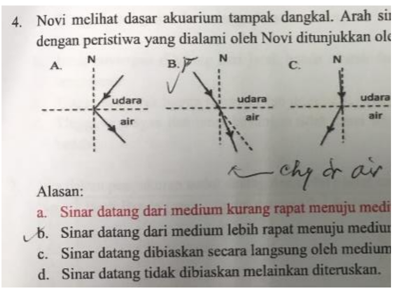
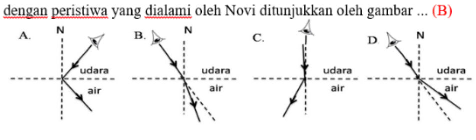
We carried the expert validation stage using a questionnaire filled in by two science teachers and three science lecturers. This questionnaire comprises 11 items aspect reviewed. The questionnaire results were summed, and we calculated the percentage. The aspects to assess the TTMCT are content material, construction of the test, and language. The percentages of the results are shown in Table 4.3.

Table 4.3. Expert validation results of the TTMCT

Aspects reviewed		Percentage	Average
A. Content material	Questions in accordance with the syllabus	95%	90.6%
	answer options are logic	86.3%	
	Only one correct answer	90.6%	
B. Construction of test	Questions are formulated clearly	91.3%	93.5%
	Picture/graph/table are clear	85.6%	
	The length of the option is relatively the same	90.6%	
	The options of answer do not use the statement "all answers are correct," or "all answers are wrong"	100%	
	Options of answers in the form of numbers or time arranged in sequence	100%	
C. Language	Using standard language	95%	94.1%
	Using communicative language	92.3%	
	Using the appropriate word in science term	95%	

Table 4.3 shows the results of the average percentage of the overall TTMCT assessment. The results of validation by experts showed: (1) 90.6% of content material in the TTMCT are in accordance with the indicators in the science syllabus related to light and optical instrument concepts; (2) 93.5% construction of the questions in the TTMCT are in accordance with the guided from National Education Standards Board in Indonesia; (3) 94.1 % of the questions in the TTMCT used language that is in accordance with the rules of Indonesian language. The experts were not only filling the questionnaire but also giving suggestions to improve TTMCT. Results of suggestions from experts to improve TTMCT are shown in Table 4.4.

Table 4.4. Results of suggestions from experts to improve TTMCT

No	Suggestions	Improvement of TTMCT
1.	Add the clarity of the questions.  dihasilkan (Gambar 1). berikut ini, yang benar 1. Definisi dari cahaya adalah .... A. Cahaya termasuk gelombang elektromagnetik B. Cahaya termasuk gelombang mekanik C. Cahaya menempuh jarak yang tak terhingga D. Cahaya termasuk gelombang mekanik alasan: a. Cahaya memiliki kecepatan yang tak terbatas b. Cahaya dapat merambat di ruang hampa c. Cahaya dapat menembus semua benda d. Cahaya dapat merambat jika ada medium	Revising the TTMCT by adding the clarity of the questions. 1. Definisi dari cahaya berikut ini yang benar adalah .... A. Cahaya termasuk gelombang elektromagnetik B. Cahaya termasuk gelombang mekanik C. Cahaya menempuh jarak yang tak terhingga D. Cahaya termasuk gelombang mekanik alasan: a. Cahaya memiliki kecepatan yang tak terbatas b. Cahaya dapat merambat di ruang hampa c. Cahaya dapat menembus semua benda d. Cahaya dapat merambat jika ada medium
2.	Revise the structure of the sentence according to the standard rule of the assessment.  *Perhatikan Gambar 9 untuk membantu mengerjakan soal nomor 23-25!* 23. Berdasarkan Gambar 9, cacat mata presbiopi disebabkan karena bagian mata nomor ... sudah tidak berfungsi dengan baik. A. 4 C. 1 B. 6 D. 5 Alasan: a. Cacat mata presbiopi dikarenakan daya akomodasi yang mulai lemah b. Cacat mata presbiopi dikarenakan lensa mata terlalu cembung c. Kornea mata yang kotor menyebabkan seseorang dapat mengalami presbiopi d. Kornea mata yang tidak dapat berakomodasi merupakan penyebab utama presbio Gambar 9. Bagian-bagian Mata Manusia	Revising the structure of the sentence according to the standard rule of the assessment. *Perhatikan Gambar 9 untuk membantu mengerjakan soal nomor 23-25!* 23. Berdasarkan Gambar 9, cacat mata presbiopi disebabkan oleh tidak berfungsinya bagian mata nomor .... A. 4 C. 1 B. 6 D. 5 Alasan: a. Cacat mata presbiopi dikarenakan daya akomodasi yang mulai lemah b. Cacat mata presbiopi dikarenakan lensa mata terlalu cembung c. Kornea mata yang kotor menyebabkan seseorang dapat mengalami presbiopi d. Kornea mata yang tidak dapat berakomodasi merupakan penyebab utama presbiop  Gambar 9. Bagian-bagian Mata Manusia
3	Improve the sentence in the reading text according to the standard rules.  *Bacalah teks berikut ini untuk mengerjakan soal nomor 13dan14!* Resti, siswi kelas VIII sedang melihat poster di dinding sekolahnya. Dia tidak dapat melihat dengan jelas tulisan di poster yang berjarak 100 cm, sedangkan teman di sebelahnya dapat melihat tulisan artikel di poster dengan jelas dengan jelas. 14. Berdasarkan teks, Resti menderita cacat mata .... A. emetropi C. miopi B. hipermetropi D. presbiopi Alasan: a. Bentuk bola mata terlalu cembung, tetapi dapat memipih, sehingga bayangan jatuh tepat di retina b. Bentuk bola mata terlalu pipih sehingga bayangan jatuh di belakang retina sehingga tidak dapat melihat jarak dekat. c. Bentuk bola mata yang pipih, mengakibatkan bayangan jatuh di depan retina sehingga tidak dapat melihat jarak dekat d. Bentuk bola mata terlalu cembung dan tidak dapat memipih, akibatnya bayangan benda jatuh di depan retina	Revising the sentence in the reading text according to the standard rules. *Bacalah teks berikut ini untuk mengerjakan soal nomor 13dan14!* Resti, siswi kelas VIII sedang melihat poster di dinding sekolah. Dia tidak dapat melihat dengan jelas tulisan di poster yang berjarak 100 cm, sedangkan teman di sebelahnya dapat melihat tulisan artikel di poster dengan jelas. 14. Berdasarkan teks, Resti menderita cacat mata .... A. emetropi C. miopi B. hipermetropi D. presbiopi Alasan: a. Bentuk bola mata terlalu cembung, tetapi dapat memipih, sehingga bayangan jatuh tepat di retina b. Bentuk bola mata terlalu pipih sehingga bayangan jatuh di belakang retina sehingga tidak dapat melihat jarak dekat. c. Bentuk bola mata yang pipih, mengakibatkan bayangan jatuh di depan retina sehingga tidak dapat melihat jarak dekat d. Bentuk bola mata terlalu cembung dan tidak dapat memipih, akibatnya bayangan benda jatuh di depan retina
4	Add 'eye' to make refraction picture more clear  4. Novi melihat dasar akuarium tampak dangkal. Arah si... dengan peristiwa yang dialami oleh Novi ditunjukkan ol... A. B. C. udara air Alasan: a. Sinar datang dari medium kurang rapat menuju medi... b. Sinar datang dari medium lebih rapat menuju mediu... c. Sinar datang dibiaskan secara langsung oleh medium d. Sinar datang tidak dibiaskan melainkan diteruskan.	Adding "eye" in the light refraction process 4. Novi melihat dasar akuarium tampak dangkal. Arah sinar bias yang benar ses dengan peristiwa yang dialami oleh Novi ditunjukkan oleh gambar ... (B)  Alasan: a. Sinar datang dari medium kurang rapat menuju medium lebih rapat. b. Sinar datang dari medium lebih rapat menuju medium kurang rapat. c. Sinar datang dibiaskan secara langsung oleh medium kurang rapat. d. Sinar datang tidak dibiaskan melainkan diteruskan.

4.3.3.2. Pilot study

To validate TTMCT, we conducted a pilot study. We administered the final version of the TTMCT to 95 students in grade 9th Junior High School. All of them had studied light and optical instrument concepts in grade 8th. The aim of the pilot study was to test the effectiveness of the TTMCT regarding content coverage and language appropriateness. From the pilot test, it was identified that students needed about 80 minutes to complete answering the TTMCT which comprises 25 items question. Figure 4.4 shows an example of the response combinations selected by the students.

1. What is the definition of light? A. Light is an electromagnetic wave B. Light is a mechanical wave C. Light travels an unlimited distance D. Light is a longitudinal wave Reason: a. Light has an infinite speed b. Light can travel through a vacuum c. Light can pass through all object d. Light can propagate if there is a medium	2. We can see the fish in the aquarium. The fact about the relationship between light and the ability of the eye to see objects is... A. The eye can see objects because the object can absorb the received light B. The eye can see objects because the objects reflected light, so that light enters the eye C. The eye can see objects because the object refracted light, so that light enters the eye D. The eye can see objects because the eye nerves can see objects, so the ability of the eye to see the object has no relationship with light Reason: a. Eyes can see even without light b. Eyes can produce light, so the eyes can see objects c. The light coming from a light source directly enters our eyes d. If there is no light to reflect at an object, no object can be seen

Item	Answer option	Reason option					Total
		a	b	c	d	blank	
Q1	A	*23,16*	**56,84***	3,16	0,00	0,00	83,16
	B	1,05	4,21	2,11	0,00	0,00	7,37
	C	1,05	3,16	1,05	0,00	0,00	5,26
	D	2,11	2,11	0,00	0,00	0,00	4,21
	blank	0,00	0,00	0,00	0,00	0,00	0,00
Q2	A	3,16	1,05	2,11	0,00	0,00	6,32
	B	12,63	8,42	12,63	**35,79***	0,00	69,47
	C	4,21	2,11	4,21	3,16	0,00	13,68
	D	2,11	3,16	2,11	3,16	0,00	10,53
	Blank	0,00	0,00	0,00	0,00	0,00	0,00

Note: Figure in bold and with an asterisk indicates the correct answer. Texts in italics indicate misconception (>15%).

Figure 4.4. The example of the item TTMCT and percentage of students selecting each response combination for item number 1 and 2 dealing with the properties of the light

We carried a pilot study of the TTMCT with 95 students in grade 9th Junior High School in the 2017-2018 academic years. All of them had studied light and optical instruments in grade 8th. Table 4.5 gives the percentage of students selecting each response combination for TTMCT about light and optical instrument concepts.

Table 4.5. Responses by grade 9th students and percentage for each item questions

Item	Answer option	Reason option					Total
		a	b	c	d	blank	
Q1	A	*23,16*	**56,84***	3,16	0,00	0,00	83,16
	B	1,05	4,21	2,11	0,00	0,00	7,37
	C	1,05	3,16	1,05	0,00	0,00	5,26
	D	2,11	2,11	0,00	0,00	0,00	4,21
	blank	0,00	0,00	0,00	0,00	0,00	0,00
Q2	A	3,16	1,05	2,11	0,00	0,00	6,32
	B	12,63	8,42	12,63	**35,79***	0,00	69,47
	C	4,21	2,11	4,21	3,16	0,00	13,68
	D	2,11	3,16	2,11	3,16	0,00	10,53
	blank	0,00	0,00	0,00	0,00	0,00	0,00
Q3	A	*28,42*	2,11	5,26	3,16	0,00	38,95
	B	0,00	3,16	*38,95*	1,05	0,00	43,16
	C	9,47	0,00	4,21	0,00	0,00	13,68
	D	1,05	0,00	**3,16***	0,00	0,00	4,21
	blank	0,00	0,00	0,00	0,00	0,00	0,00
Q4	A	2,11	3,16	11,58	1,05	0,00	17,89
	B	**13,68***	10,53	*25,26*	2,11	1,05	52,63
	C	2,11	2,11	6,32	0,00	0,00	10,53
	D	12,63	2,11	4,21	0,00	0,00	18,95
	blank	0,00	0,00	0,00	0,00	0,00	0,00
Q5	A	5,26	1,05	3,16	1,05	0,00	10,53
	B	9,47	7,37	13,68	3,16	1,05	34,74
	C	14,74	**6,32***	5,26	4,21	1,05	31,58
	D	11,58	6,32	0,00	2,11	2,11	22,11
	blank	0,00	0,00	0,00	0,00	1,05	1,05
Q6	A	1,05	0,00	4,21	2,11	0,00	7,37
	B	*16,84*	10,53	2,11	10,53	0,00	40,00
	C	0,00	0,00	0,00	3,16	1,05	4,21
	D	8,42	4,21	**25,26***	10,53	0,00	48,42
	blank	0,00	0,00	0,00	0,00	0,00	0,00
Q7	A	2,11	4,21	0,00	1,05	0,00	7,37
	B	6,32	*16,84*	7,37	**47,37***	1,05	78,95
	C	2,11	2,11	3,16	3,16	0,00	10,53
	D	0,00	1,05	1,05	1,05	0,00	3,16
	blank	0,00	0,00	0,00	0,00	0,00	0,00

Item	Answer option	Reason option					Total
		a	b	c	d	blank	
Q8	A	6,32	**14,74***	4,21	3,16	1,05	29,47
	B	12,63	5,26	2,11	2,11	1,05	23,16
	C	7,37	1,05	4,21	0,00	1,05	13,68
	D	10,53	5,26	5,26	11,58	0,00	32,63
	blank	0,00	0,00	0,00	0,00	1,05	1,05
Q9	A	11,58	8,42	2,11	10,53	1,05	33,68
	B	2,11	5,26	**25,26***	2,11	1,05	35,79
	C	7,37	3,16	2,11	3,16	0,00	15,79
	D	3,16	3,16	2,11	3,16	1,05	12,63
	blank	0,00	0,00	0,00	0,00	2,11	2,11
Q10	A	2,11	2,11	2,11	0,00	0,00	6,32
	B	10,53	*18,95*	*22,11*	4,21	0,00	55,79
	C	1,05	**21,05***	5,26	4,21	0,00	31,58
	D	0,00	3,16	1,05	1,05	0,00	5,26
	blank	0,00	0,00	0,00	0,00	1,05	1,05
Q11	A	1,05	1,05	3,16	0,00	0,00	5,26
	B	1,05	7,37	1,05	6,32	0,00	15,79
	C	*17,89*	9,47	12,63	5,26	0,00	45,26
	D	0,00	3,16	**26,32***	3,16	0,00	32,63
	blank	0,00	0,00	0,00	0,00	1,05	1,05
Q12	A	*25,26*	*15,79*	14,74	**16,84***	0,00	72,63
	B	2,11	3,16	4,21	2,11	0,00	11,58
	C	0,00	0,00	6,32	0,00	1,05	7,37
	D	3,16	1,05	2,11	0,00	0,00	6,32
	blank	0,00	0,00	0,00	0,00	2,11	2,11
Q13	A	7,37	2,11	4,21	3,16	1,05	17,89
	B	**29,47***	4,21	5,26	4,21	1,05	44,21
	C	8,42	4,21	9,47	1,05	0,00	23,16
	D	4,21	0,00	4,21	3,16	1,05	12,63
	blank	0,00	0,00	0,00	0,00	2,11	2,11
Q14	A	0,00	5,26	1,05	0,00	0,00	6,32
	B	0,00	8,42	0,00	9,47	0,00	17,89
	C	9,47	11,58	14,74	**29,47***	5,26	70,53
	D	1,05	2,11	0,00	2,11	0,00	5,26
	blank	0,00	0,00	0,00	0,00	0,00	0,00
Q15	A	**9,47***	10,53	3,16	9,47	3,16	35,79
	B	*15,79*	9,47	5,26	3,16	2,11	35,79
	C	8,42	4,21	2,11	4,21	1,05	20,00
	D	1,05	3,16	0,00	2,11	0,00	6,32
	blank	0,00	0,00	0,00	0,00	2,11	2,11
Q16	A	14,74	1,05	3,16	4,21	0,00	23,16
	B	14,74	3,16	**32,63***	4,21	1,05	55,79
	C	1,05	3,16	3,16	0,00	0,00	7,37

Item	Answer option	Reason option					Total
		a	b	c	d	blank	
	D	6,32	2,11	2,11	1,05	0,00	11,58
	blank	0,00	0,00	0,00	0,00	2,11	2,11
Q17	A	5,26	1,05	1,05	3,16	0,00	10,53
	B	6,32	9,47	3,16	7,37	2,11	28,42
	C	3,16	0,00	0,00	0,00	0,00	3,16
	D	**25,26***	*17,89*	1,05	9,47	2,11	55,79
	blank	0,00	0,00	0,00	0,00	2,11	2,11
Q18	A	*21,05*	4,21	4,21	10,53	0,00	40,00
	B	7,37	2,11	3,16	3,16	0,00	15,79
	C	5,26	4,21	6,32	**13,68***	3,16	32,63
	D	1,05	1,05	2,11	1,05	2,11	7,37
	blank	0,00	0,00	0,00	0,00	4,21	4,21
Q19	A	0,00	1,05	4,21	2,11	1,05	8,42
	B	3,16	1,05	0,00	6,32	0,00	10,53
	C	1,05	7,37	7,37	2,11	2,11	20,00
	D	4,21	*17,89*	**23,16***	10,53	2,11	57,89
	blank	0,00	0,00	0,00	0,00	3,16	3,16
Q20	A	*26,32*	**43,16***	2,11	5,26	3,16	80,00
	B	0,00	3,16	0,00	0,00	0,00	3,16
	C	2,11	5,26	3,16	0,00	1,05	11,58
	D	0,00	2,11	0,00	1,05	0,00	3,16
	blank	0,00	0,00	0,00	0,00	2,11	2,11
Q21	A	5,26	0,00	6,32	6,32	0,00	17,89
	B	**9,47***	2,11	10,53	*16,84*	2,11	41,05
	C	3,16	4,21	9,47	2,11	1,05	20,00
	D	2,11	1,05	7,37	7,37	1,05	18,95
	blank	0,00	0,00	0,00	0,00	2,11	2,11
Q22	A	8,42	**17,89***	2,11	2,11	1,05	31,58
	B	5,26	7,37	4,21	1,05	0,00	17,89
	C	*24,21*	11,58	4,21	1,05	1,05	42,11
	D	1,05	1,05	4,21	0,00	1,05	7,37
	blank	0,00	0,00	0,00	0,00	1,05	1,05
Q23	A	9,47	1,05	1,05	5,26	1,05	17,89
	B	*17,89*	0,00	1,05	4,21	1,05	24,21
	C	*17,89*	3,16	2,11	2,11	0,00	25,26
	D	**14,74***	11,58	4,21	0,00	1,05	31,58
	blank	0,00	0,00	0,00	0,00	1,05	1,05
Q24	A	12,63	0,00	4,21	*21,05*	1,05	38,95
	B	3,16	3,16	2,11	5,26	0,00	13,68
	C	0,00	1,05	4,21	**12,63***	0,00	17,89
	D	8,42	2,11	6,32	6,32	1,05	24,21
	blank	0,00	0,00	0,00	0,00	5,26	5,26
Q25	A	5,26	5,26	2,11	5,26	1,05	18,95

Item	Answer option	Reason option					Total
		a	**b**	**c**	**d**	**blank**	
	B	13,68	3,16	13,68	6,32	1,05	37,89
	C	**5,26***	*21,05*	4,21	0,00	0,00	30,53
	D	1,05	1,05	3,16	2,11	0,00	7,37
	blank	0,00	0,00	0,00	0,00	5,26	5,26

Note: Number in bold and with an asterisk indicates the correct answer. Number in italics indicate major misconceptions (>15%).

In a traditional multiple-choice test with four choices, the chance of guessing the correct answer is 25 percent. But, in a TTMCT the chance of guessing is 6.25 percent. By lessening the chance of the guessing from 25 percent to 6.25 percent, the arithmetic means of the students might decrease. Treagust (1988) stated that the development of a two-tier diagnostic test to measure students' conceptions. The first tier of each item in the test is a multiple-choice question related to proportional statements, and the second tier of each item is composed of a multiple-choice set of reasons for the answer to the first tier. The set of reasons includes the scientific answer and misconceptions by students. A student's answer to an item was correct if the student selected both the correct answer and the correct reason. We tested items of the TTMCT for both correct and incorrect response combinations selected by the students.

Misconceptions are significant and common if we found them in over 10% of the students' sample (Peterson, 1986; Tan et al., 2005). This research used over 15% to determine students' misconceptions because to be more convincing the degree of the misconceptions. Table 4.6 shows the summary of significant common misconceptions of students in light and optical instrument concepts using TTMCT. Twenty-two misconceptions were identified and grouped under the headings of 'the properties of light', 'the formation of the image in mirrors and lenses', 'optical instruments', 'human eye', and 'eye disorders.'

Table 4.6. Students' misconceptions from the administration of the TTMCT

	Students' misconceptions	Choice combination
The properties of light		
M1	Light is an electromagnetic wave and has an infinite speed	Q1 (A-a)
M2	A white light bulb is a type of monochromatic lights and can be broken down into other colors through the process of light diffraction	Q3 (A-a)
M3	A white light bulb is a type of monochromatic lights and can be broken down into other colors through the process of light dispersion	Q3 (B-c)
M4	Light can refract towards the normal when light ray is directly refracted by the rarer medium	Q4 (B-c)
The formation of an image in mirrors and lenses		
M5	The height of an image is the same as the height of the object, while the distance of an image is two times the distance from the object	Q6 (B-a)
M6	The distance of the object affects the magnitude of the incidence and reflection angles	Q7 (B-b)
M7	The magnification of an image is the result of the height of the object with the height of the image	Q12 (A-a)
M8	The magnification of an image is the result of the height of the object with the distance of the image	Q12 (A-b)
Optical instruments		
M9	In a convex lens, if the object position is closer to the lens then characteristics of the image are virtual, upright and enlarge	Q18 (A-a)
M10	A microscope consists of two convex lenses, the ocular lens (near the object) and the objective lens (near the eye)	Q20 (A-a)
M11	The similarity between human eyes and camera is both of them have a concave-convex lens	Q21 (B-d)
M12	The lens in a camera has a function to controls the accommodating power that has similar function with iris in the human eye	Q22 (C-a)
Human Eye		
M13	The eye lens is a part of the eye which serves as an image catcher	Q10 (B-b)
M14	The eye lens is a part of the eye that refracts the light so that it can give the impression of seeing.	Q10 (B-c)
M15	The pupil is a part of the human eye that has a function to focus the light into the retina	Q11 (C-a)
M16	Eye accommodating happens when the object is far, the lens of the eye is flattened; while when the object is close, the muscles in the eye are relaxing and the lens of the eye is bulging	Q19 (D-b)
M17	Presbyopia is caused by the cornea is not working properly	Q23 (B-a)
M18	Presbyopia is caused by the pupil is not working properly	Q23 (C-a)
M19	The aqueous humor is located in the iris	Q24 (A-d)
Eye Disorders		
M20	Myopia can help using positive eyeglasses	Q15 (B-a)
M21	The characteristic of nearsighted (hypermetropia) is an image formation behind the retina and caused by the shape of the eyeball is too convex	Q17 (D-b)
M22	Myopia can be helped by the concave lens which is a positive lens	Q25 (C-b)

4.4. TTMCT item analysis

The aims of this study were to develop a TTMCT to assess students' conceptual understanding and to identify students' misconceptions of light and optical instrument concepts. Item Analysis is related to several items of statistical analysis in analyzing the characteristics and features of a test. According to the theory of test development, the TTMCT that have been made need to be analyzed for validity, reliability, item difficulty and discrimination index.

4.4.1. Validity analysis

The validity of an assessment is the level in which a test measures what it claims to measure. It is the most critical dimension of test development. Validating the TTMCT demanded to look at several different types of validity during its development. From several studies about test development, it is common to analyzed item validity. Item validity is the extent to which an individual item measures what it purports to measure. Validity test was analyzed by correlating the scores obtained by students in the test with the total score obtained. For small samples, validity calculated using:

$$r_{xy} = \frac{N(\Sigma XY) - (\Sigma X)(\Sigma Y)}{\sqrt{(N\Sigma X^2 - (\Sigma X)^2)(N\Sigma Y^2 - (\Sigma Y)^2)}}$$

Where:

r = Pearson's correlation coefficient

N = number of paired scores

X = score of the first variable

Y = score of the second variable

XY = the product of the two paired scores

If the r_{count} value more than r_{table} value, the question in the TTMCT is valid. On the contrary, if the r_{count} value less than r_{table} value the questions in the TTMCT is invalid. Based on Table 4.7 the valid items are Q1, Q2, Q3, Q4, Q6, Q7, Q8, Q9, Q10, Q11, Q12, Q13, Q15, Q16, Q17, Q18, Q19, Q20, Q22, Q23, Q24, and Q25. Meanwhile, the invalid items are Q5, Q14 and Q21. In this study, the valid questions were used in the research and the invalid questions were revised based on the students' ability and curricullum content. Table 4.7 shows the SPSS results of analysis item validity of the TTMCT.

Table 4.7. Validity analysis of the TTMCT

Item	r_{count}	r_{table}	Criteria
Q1	0.287	0.207	valid
Q2	0.441	0.207	valid
Q3	0.408	0.207	valid
Q4	0.323	0.207	valid
Q5	0.119	0.207	invalid
Q6	0.563	0.207	valid
Q7	0.308	0.207	valid
Q8	0.413	0.207	valid
Q9	0.600	0.207	valid
Q10	0.534	0.207	valid
Q11	0.517	0.207	valid
Q12	0.445	0.207	valid
Q13	0.515	0.207	valid
Q14	0.067	0.207	invalid
Q15	0.312	0.207	valid
Q16	0.398	0.207	valid
Q17	0.456	0.207	valid
Q18	0.489	0.207	valid
Q19	0.291	0.207	valid
Q20	0.401	0.207	valid
Q21	0.06	0.207	invalid
Q22	0.486	0.207	valid
Q23	0.238	0.207	valid
Q24	0.448	0.207	valid
Q25	0.311	0.207	valid

*) If the $r_{count} > r_{table}$ indicated that the item in TTMCT is valid.

4.4.2. Reliability analysis

Reliability refers to the consistency of the test scores and the extent to which the measures are free from errors. There are different reliability estimates, but in this study, the internal consistency of the test scores was estimated by calculating the Cronbach Alpha Coefficient. According to Fraenkel & Wallen (2011), there is some benchmark to test the reliability coefficient. Cronbach's Alpha value is interpreted by the criteria that can be seen in Table 4.8.

Table 4.8. Criteria of the Cronbach's Alpha value

No.	Category	Reliability
1.	0.800 – 1.000	Very high
2.	0.600 – 0.799	High
3.	0.400 – 0.599	Moderate
4.	0.200 – 0.399	Low
5.	0.000 – 0.199	Very low

For many achievement tests, the reliability coefficients are typically 0.90 or higher, while for many classroom achievements test the reliability coefficient is 0.70 or higher. The ideal level test reliability is a Cronbach's alpha (α) ≥ 0.70 (Crocker & Algina, 2008). The results analysis of Cronbach's Alpha value of the TTMCT in this study can be seen in Figure 4.5.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.759	.746	25

Figure 4.5. Reliability analysis

The analysis of the reliability is important to examine the consistency of the items that instruments measure. Based on the SPSS analysis, the reliability of the TTMCT was 0.759 (in the high-reliability category). Hence, it can be concluded that the items in the TTMCT were reliable to assess the understanding of light and optical instruments concept.

4.4.3. Item difficulty analysis

Item difficulty is the proportion of students who answer an item correctly. Nearly all test score parameters are affected by item difficulty. An index measure it called difficulty index. We calculated item difficulty for each item. Item difficulty is the average score for a particular exam question. It shows how much the ratio of the students answers the item correctly. It ranges from 0.00 to 1.00. A high item difficulty (for example above 0.50) shows most of the students answered the item correctly. The higher the value of item difficulty, the easier the test question. The goal was to have a wide range of item difficulty on the TTMCT varying from easy to difficult. The level of difficulty of the question is shown by a number called difficulty index that can be calculated with the formula:

$$\mathrm{DI} = \frac{B}{JS} \qquad \text{(Arikunto S, 2002:208)}$$

Information:

DI = difficulty index of the question

B = mean of each question score

JS = maximum score

The criteria related to the difficulty index of this question are as follows:

a. Question with the difficulty index of 0.00 ≤ P < 0.30 is a difficult item.

b. Question with the difficulty index of 0.30 ≤ P < 0.70 is a moderate item.

c. Question with the difficulty index of 0,70 ≤ P ≤ 1,00 is a easy item.

The difficulty level of many individual items will differ depending on the purposes for which one is testing. For the achievement test, the average index of difficulty is 0.5 or 50 percent that may be desirable. The results of the difficulty index analysis are presented in Table 4.9.

Based on Table 4.9, the analysis of the results of the level of difficulty in the TTMCT for items with difficult criteria are Q5, Q8, Q21, and Q25. Meanwhile, for items with moderate criteria are Q2, Q3, Q4, Q6, Q7, Q9, Q10, Q11, Q12, Q13, Q14, Q15, Q16, Q17, Q18, Q19, Q20, Q22, Q23, and Q24. Only Q1 which is in the easy criteria.

Table 4.9. Results analysis of the level of difficulty in the TTMCT

Item	Difficulty index	Criteria
Q1	0.716	easy
Q2	0.512	moderate
Q3	0.358	moderate
Q4	0.386	moderate
Q5	0.249	difficult
Q6	0.372	moderate
Q7	0.607	moderate
Q8	0.288	difficult
Q9	0.319	moderate
Q10	0.414	moderate
Q11	0.389	moderate
Q12	0.382	moderate
Q13	0.488	moderate
Q14	0.512	moderate
Q15	0.368	moderate
Q16	0.463	moderate
Q17	0.456	moderate
Q18	0.302	moderate
Q19	0.411	moderate
Q20	0.632	moderate
Q21	0.253	difficult
Q22	0.375	moderate
Q23	0.505	moderate
Q24	0.368	moderate
Q25	0.270	difficult

4.4.4. Item discrimination analysis

The item discrimination index shows how a test item discriminates between high scores and low scores. If a test has items with high discrimination indexes, it shows that high scorers on the exam answer correctly whereas low scorers answer the items incorrectly. Discrimination index can range from 1.00 (an item which discriminates perfectly) through 0.00 (an item which does not discriminate at all). Table 4.10 shows the criteria of the discrimination index.

Table 4.10. Criteria of discrimination index

Discrimination index	Criteria
0.00 – 0.20	Bad
0.21 – 0.40	Moderate
0.41 – 0.70	Good
0.71 – 1.00	Very good

A high discrimination index shows that the students who had high test scores got the item correct, whereas students who had low test scores got the item incorrect. Table 4.11 shows the results of the discrimination index analysis.

Table 4.11. Analysis of the discrimination index of the TTMCT

Item	Discrimination index	Criteria
Q1	0.287	moderate
Q2	0.441	good
Q3	0.408	good
Q4	0.323	moderate
Q5	0.119	bad
Q6	0.563	good
Q7	0.308	moderate
Q8	0.413	good
Q9	0.600	good
Q10	0.543	good
Q11	0.517	good
Q12	0.445	good
Q13	0.515	good
Q14	0.067	bad
Q15	0.312	moderate
Q16	0.398	moderate
Q17	0.456	good
Q18	0.489	good
Q19	0.291	moderate
Q20	0.401	good
Q21	0.006	bad
Q22	0.486	good
Q23	0.238	moderate
Q24	0.448	good
Q25	0.311	moderate

4.4.5. Recapitulation of the results of the item analysis

After getting data on validity, reliability, level of difficulty and discrimination index of the question, 25 items were obtained that could be used with valid criteria and had a discrimination index over 0.2 and the rest were not used. We present the results of item analysis in Table 4.12 with test reliability is 0.76 with high criteria.

Table 4.12. Results analysis of item question

Question	Item validity	Item difficulty	Item discrimination	Decision
Q1	valid	easy	moderate	can be used
Q2	valid	moderate	good	can be used
Q3	valid	moderate	good	can be used
Q4	valid	moderate	moderate	can be used
Q5	invalid	difficult	bad	can be used with revision
Q6	valid	moderate	good	can be used
Q7	valid	moderate	moderate	can be used
Q8	valid	difficult	good	can be used
Q9	valid	moderate	good	can be used
Q10	valid	moderate	good	can be used
Q11	valid	moderate	good	can be used
Q12	valid	moderate	good	can be used
Q13	valid	moderate	good	can be used
Q14	invalid	moderate	bad	can be used with revision
Q15	valid	moderate	moderate	can be used
Q16	valid	moderate	moderate	can be used
Q17	valid	moderate	good	can be used
Q18	valid	moderate	good	can be used
Q19	valid	moderate	moderate	can be used
Q20	valid	moderate	good	can be used
Q21	invalid	difficult	bad	can be used with revision
Q22	valid	moderate	good	can be used
Q23	valid	moderate	moderate	can be used
Q24	valid	moderate	good	can be used
Q25	valid	difficult	moderate	can be used

Item analysis is a simple, yet valuable procedure performed after the examination providing information regarding the reliability and validity of a test. Based on Table 4.12, twenty-two item questions in the TTMCT were valid and can measure the conceptual understanding of light and optical instrument concepts. However, three of the item questions were invalid and need to be changed. To measure conceptual understanding, these item questions were revised and changed in the sentence's structure and answer options.

4.5. Discussion

There are several reasons for developing TTMCT in this study. The previous literature showed that there are various advantages of using TTMCT. Chen and Lin (2003) found that the TTMCT provided a reliable and valid pencil-and-paper, easy to score instruments for the teacher to evaluate students' idea better. This test has been used to evaluate students' misconceptions (Treagust, 1988) and very useful as the instruments that provide the teachers with students' understanding of a particular science concept (Treagust & Chandrasegaran, 2007). The test is more administered and readily scored than the other method (Tan & Treagust, 1999, Adadan & Savasci, 2012). The TTMCT is convenient for students to respond and more practical and valuable for teachers to use regarding reducing guesswork, allowing for large-scale administration and offering insight students' reasoning (Adadan & Savasci, 2012).

We thought the misconceptions about light and optical instruments to be due to a lack of understanding of concepts and the application of wrong reasoning. The complexity and difficulty of the light and optical instrument concepts can cause the students' misconceptions. In the learning process, students will try to connect the new knowledge to their cognitive structures. If the students have misconceptions, these will interfere with their learning and they will difficult to connect new knowledge with their existing knowledge. Because of this condition, students will have difficulty in achieving conceptual understanding in the learning process. Thus, the teacher should guide prerequisite concepts for the students as the bridging between students' prior knowledge and the understanding of the concept being learned (Tsui & Treagust, 2010).

The science curriculum in Indonesia stated that the assessment directed to measure students' conceptual understanding (Widiyatmoko & Shimizu, 2018). Based on Table 4.6, the TTMCT in this research addressed conceptual understanding in five topics: (1) The properties of light (definition of light, relationship between light and vision, monochromatic and polychromatic light, light refraction and light as a transversal wave); (2) The formation of image in mirrors and lenses (the image formation in a plane mirror, the law of reflection and refraction, and image formation in a mirror); (3) Optical instruments (the image formation in the convex lens, the image formation of microscope, and similarities of human eye and camera); (4) Human eye (the parts of human eye and the accommodation of human eye); (5) Eye disorders (the eye disorders and the solution for each eye disorders).

Four misconceptions related to the properties of light were determined from the administration of the TTMCT. The misconceptions for this topic are (1) *Light is an electromagnetic wave and has an infinite speed* was held by 23% of students; (2) *White light bulb is a monochromatic light and can be broken down into other colors through the process of light diffraction* was held by 28% of students; (3) *White light bulb is a monochromatic light and can be broken down into other colors through the process of light dispersion* was held by 28% of students; (4) *Light can refract towards the normal when light ray is refracted by the rarer medium* was held by 25% of students. The misconceptions in the properties of light were supported with the results reported by Fetherstonhaugh and Treagust (1992), who investigated students' conceptual understanding of light and its properties using a 16-item diagnostic test in four areas: How lights travel?; How do we see?; How is light reflected?; How do lenses work?.

Four misconceptions related to the formation of an image in mirrors and lenses were determined. The misconceptions for this topic are (1) *the height of an image is the same as the height of the object, while the distance of an image is two times the distance from the object* was held by 17% of students; (2) *The distance of the object affects the magnitude of the incidence angle and reflection angle* was held by 17% of students; (3) *The magnification of an image results from the height of the object with the height of the image* was held by 25% of students; (4) *The magnification of an image results from the height of the object with the distance of the image* was held by 16% of students. The misconceptions found in the topic of the formation of an image in mirrors and lenses were supported with the results reported by Chen et al. (2002) that developed a two-tier diagnostic test to identify the misconceptions of Taiwanese high school students about image formation by a plane mirror. Kaewkhong et al. (2010) stated that students in Thailand had significant misconceptions about the direction of propagation of light, how light refracts at an interface and how to determine the position of an image. All the misconceptions about image formation by a mirror are based on two fundamental aspects of image formation. The first aspect is the position of the image and its characteristics. The second aspect is the visual field involving the relationship between the observer's position, the position of the object and the position of the image.

Four misconceptions related to optical instruments were determined. The misconceptions occur for this topic are: (1) *in a convex lens, if the object position in closer to the lens then characteristic image is virtual, upright and enlarge* was held by 21% students; (2) *microscope comprises two convex lenses, the ocular lens (near the object) and the objective lens (near the eye)* was held by 26% of students; (3) *the similarity between human eyes and camera is both of them have concave-convex lens* was held by 17% of students; (4) *the lens in a camera has function to controls the accommodating power that has same function with iris in the human eye* was held by 24 % of students.

Misconceptions identified in this study related to the human eye are: (1*) the eye lens is a part of the eye which serves as an image catcher* was held by 19% of students; (2) *the eye lens is a part of the eye that refracts the light so it can give the impression of seeing* was held by 22% of students; (3) *the pupil is a part of the human eye that has a function to focus the light onto the retina* was held by 18% of students; (4) *the aqueous humor is located in the iris* was held by 21% of students. Related to eye disorder, misconceptions identified in this study are: (1) *presbyopia is caused by the cornea is not working properly* was held by 18% of students; (2) *presbyopia is caused by the pupil is not working properly* was held by 18% of students; (3) *Myopia can be helped using positive eyeglasses* was held by 16% of students. The misconceptions found in optical instruments and human eye were supported by the results reported by Kutluay (2005) that developed a test to diagnose eleventh-grade students' misconceptions about geometrical optics in Turkey.

The findings in this study showed that students hold varies misconceptions in all topics about light and optical instrument concepts. The difficulty and complexity of the concepts, language used, daily-life experiences, and science textbooks arose these misconceptions. This confirms that students come to school with various knowledge about this concept based on their daily experiences.

The TTMCT is a valid and reliable instrument to assess conceptual understanding or misconception. The validity of the TTMCT was analyzed by a panel of experts who judges that is measured conceptual understanding. Difficulty indices ranged from 0.249 to 0.716, with a mean of 0.416, providing a wide range of difficulty in the items. Discrimination indices ranged from 0.006 to 0.600, with a mean of 0.375, showing in the moderate criteria. The Cronbach's alpha reliability coefficient of the TTMCT was found to be 0.76. It means that at least 76% of the variance in students' total scores was because of the variance in the true scores of the students (Crocker & Algina, 2008). We considered this value satisfactory for the aim of the study and also consistent with other two-tier tests (Chen et al., 2002; Odom & Barrow, 1995; Tan et al., 2002). Thus, it can be concluded that the TTMCT is a valid and reliable test to measure students' conceptual understanding and identify students' misconceptions of light and optical instruments.

From the previous literature review, research in overcoming students' misconceptions involves three main steps, (a) developing diagnostic test instruments; (b) analyzing the causes of misconceptions; and (c) remediation of misconceptions (Allen, 2014). Misconceptions are difficult to replace with new, correct understandings; they consistently influence the effectiveness of further learning (Ozmen, 2004; Taber, 2009). This condition happens because of misconceptions that were difficult to change (Widarti et al., 2016). Students' misconceptions interfere with students' learning of scientific concepts (Sreypouv & Shimizu, 2017). Overcoming students' misconceptions requires teaching methods that provide chances for students to reveal their pre-concepts and dissatisfaction with their concepts, particularly about light and optical instrument concepts. According to Indonesian's national curriculum, the beginning of eighth grade in junior high school is the stage prior to receiving formal instruction about light and optical instrument concepts, and this concept is expanded and taught in the upper grade in senior high school. If the students' misconceptions about light and optical instrument concepts are not corrected, students will carry these misconceptions to the upper grades.

4.6. Conclusion

Based on the results, TTMCT can assess students' conceptual understanding and identify students' misconceptions about light and optical instrument concepts. The TTMCT could help teachers to increase students' knowledge levels and prevent students' misconceptions. Thus, TTMCT helped to improve the teaching and learning process in the science classroom. This study exhibits several limitations. One limitation was that it lacks generalizability. Since the study involving a few participants, the findings from this study may not be generalized to the other contexts.

CHAPTER 5
DEVELOPMENT OF COMPUTER SIMULATIONS TO OVERCOME STUDENTS' MISCONCEPTIONS ABOUT LIGHT AND OPTICAL INSTRUMENTS

5.1. Overview of the chapter

This chapter describes the development of computer simulations in response to Research Questions 3, which aims to develop computer simulations to overcome students' misconceptions about light and optical instrument concepts. We developed the computer simulations according to the students' misconception having assessed with TTMCT of light and optical instrument concepts. We developed the computer simulations using software Adobe Flash Professional CS6. Six science teachers reviewed the computer simulations to gain comments and suggestions for further development using a set of questionnaires which comprises 10 items with a 5-point Likert scale. The items of the questionnaires assessed computer simulations from aspects of content explanation and its deepness, display, language use, content, curriculum, and students' misconception. The results of the study showed that computer simulations are feasible for junior high school students to overcome misconceptions and to improve students' conceptual understanding of light and optical instrument concepts.

5.2. Introduction

The learning process begins when a student constructs knowledge about the phenomenon while experiencing that phenomenon in real life (Driver et al., 1994). Students come to the class with existing knowledge that they construct with their experiences and developing various ideas about scientific concepts (Maloney et al., 2001; Choi et al., 2003). The knowledge structure of a student also occurs while communicating and interacting with others (Driver, 1983). The structure of knowledge based on students' experiences tends not to be in parallel with the scientifically accepted understanding. These kinds of knowledge that contradict the scientific concepts described as misconceptions. Misconceptions are stable cognitive structures to change, affect students' conceptual understanding, and must be overcome so that students learn scientific concepts effectively (Hammer, 1996). The previous researchers show that students' misconceptions are a barrier for their further learning and may still exist even after instruction (Ayas et al., 2002; Çepni et al., 2006). These misconceptions should be overcome and replace with correct concepts to provide meaningful learning.

Overcoming students' misconceptions in science have been explored by previous researchers in the science education field. One strategy to overcome misconceptions is using the teaching method. Research related to misconceptions had shown that traditional teaching methods are not effective for overcoming students' misconceptions (Jimoyiannis & Komis, 2001). Overcoming misconceptions requires teaching methods which provide chances for students to reveal their pre-concepts and dissatisfaction with their concepts. Driver et al., (1994) suggested that effective teaching methods must be used to minimize or eliminate the misconceptions that students have. From the previous research, there are several methods for overcoming students' misconceptions in science learning, such as graphical or visual tools such as conceptual maps, using an interactive whiteboard, using drawing analysis, using inquiry activities, and using computer simulations. From these teaching methods, one of the effective methods for overcoming misconceptions is using computer simulations in the classroom (Chen et al., 2013; Ramnarain & Moosa, 2017).

A review from previous research on the effectiveness of computer simulations for supporting science teaching and learning during the past four decades by Smetana and Bell (2012) stated that simulations could help students to eliminate their misconceptions. Bell and Smetana (2008) stated that simulations provide interactive, authentic, and meaningful learning opportunities for students because simulations facilitate the learning of abstract concepts, such as light and optical instruments. This concept is one of the concepts in science learning that is difficult for students. According to Ling (2017), light and optical instruments are complex concepts that lend itself to misconceptions among teachers and students. A review of the literature on this concept has shown various difficulties in dealing with abstract concepts in the learning process. Because of these difficulties, students tend to develop misconceptions about light and optical instruments. Computer simulations provide a bridge between students' prior knowledge and the learning process of new concepts, also helping students to develop scientific understanding through an active reformulation of their misconceptions. Therefore, it is very important to develop computer simulations to overcome students' misconceptions.

5.3. Methods for developing computer simulations

The Research and Development (R & D) method was adopted for this study. Moreover, the 4-D model (Define, Design, Develop and Disseminate) was used as one type of R & D methods (Irawan et al., 2018). One of the objectives of this study was to develop computer simulations for improving students' conceptual understanding and overcoming students' misconceptions about light and optical instrument concepts. Computer simulations in this research were developed by using 4-D model shown in Figure 5.1 (Thiagarajan, Semmel, & Melvyn, 1974).

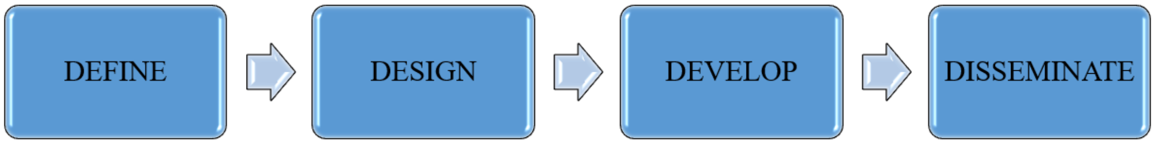


Figure 5.1. The development of computer simulations using 4-D models

5.4. Results

5.4.1. Define phase

Step 1 was the define phase. The purpose of this phase was to establish and define various terms of learning (Thiagarajan, Semmel, & Melvyn, 1974). In this phase, the first step was analyzing students' misconceptions about light and optical instrument concepts. Thus, in this phase, data of students' misconceptions about light and optical instrument concepts were assessed using the TTMCT. The results from this test were twenty-two misconceptions have found about light and optical instrument concepts. The results of percentage of students' misconceptions assessed with TTMCT are shown in Table 5.1.

Light and optical instrument concepts are taught in 8^{th} grade in junior high school according to the national science curriculum. These concepts are expanded and taught in the upper grade in senior high school. If the students' misconceptions about light and optical instrument concepts are not corrected, students will carry these misconceptions to the upper grades. Because of this reason, one of the alternative ways for removing misconceptions is using computer simulations.

Table 5.1. Percentage of students' misconceptions of light and optical instrument concepts

	Students' misconceptions	Percentage
The properties of light		
M1	Light is an electromagnetic wave and has an infinite speed	23%
M2	A white light bulb is a type of monochromatic lights and can be broken down into other colors through the process of light diffraction	28%
M3	A white light bulb is a type of monochromatic lights and can be broken down into different colors through the process of light dispersion	39%
M4	Light can refract towards the normal when light ray is directly refracted by the rarer medium	25%
The formation of an image in mirrors and lenses		
M5	The height of an image is the same as the height of the object, while the distance of an image is two times the distance from the object	17%
M6	The distance of the object affects the magnitude of the incidence and reflection angles	17%
M7	The magnification of an image is the result comparison of the height of the object with the height of the image	25%
M8	The magnification of an image is the result comparison of the height of the object with the distance of the image	16%
Optical instruments		
M9	In a convex lens, if the object position is closer to the lens then characteristics of the image are virtual, upright and enlarge	21%
M10	The microscope consists of two convex lenses, the ocular lens (near the object) and the objective lens (near the eye)	26%
M11	The similarity between human eyes and camera is both of them have a concave-convex lens	17%
M12	The lenses in a camera have a function that controls the accommodating power that has similar function with iris in the human eye	24%
Human Eye		
M13	The eye lens is a part of the eye which serves as an image catcher	19%
M14	The eye lens is a part of the eye that refracts the light so that it can give the impression of seeing.	22%
M15	The pupil is a part of the human eye that has a function to focus the light into the retina	18%
M16	Eye accommodating happens when the object is far, the lens of the eye is flattened; while when the object is close, the muscle in the eye is relaxing and the lens of the eye is bulging	18%
M17	Presbyopia is caused by the cornea is not working properly	18%
M18	Presbyopia is caused by the pupil is not working properly	18%
M19	The aqueous humor is located in the iris	21%
Eye Disorders		
M20	Myopia can be helped by using positive eyeglasses	16%
M21	The characteristic of nearsighted (hypermetropia) is an image formation behind the retina and caused by the shape of the eyeball is too convex	18%
M22	Myopia can be helped by the concave lens which is a positive lens	21%

5.4.2. Design phase

Step 2 was the design phase. This phase aimed to design computer simulations based on research purposes. Computer simulations were developed for improving students' conceptual understanding and overcoming students' misconceptions about light and optical instrument concepts. In the design phase, computer simulations were developed using software Adobe Flash Professional CS6 to overcome students' misconceptions that have been found previously in the define phase as shown in Figure 5.2. This software is a program that has been widely used by animators to produce professional animations and simulations.

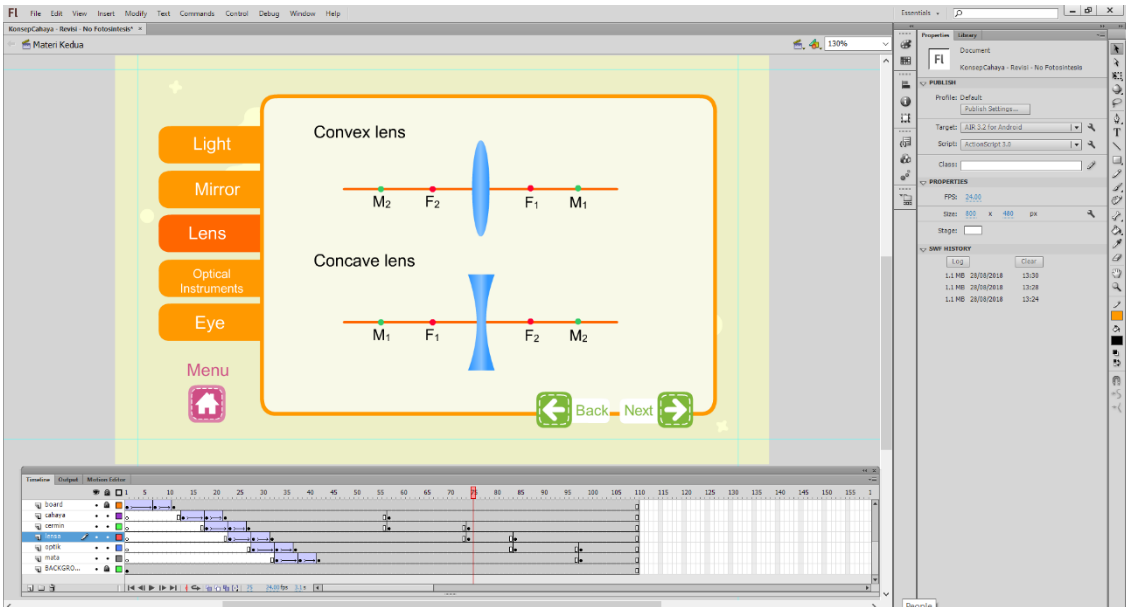
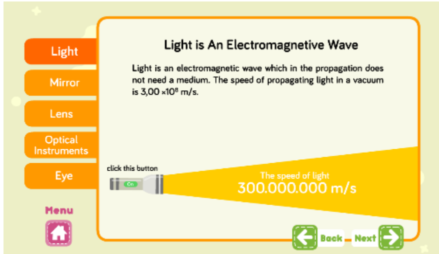
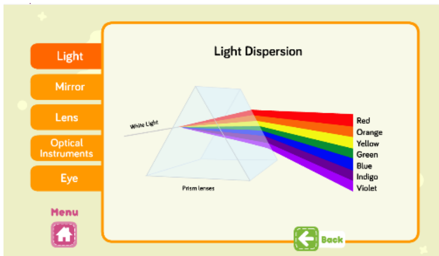
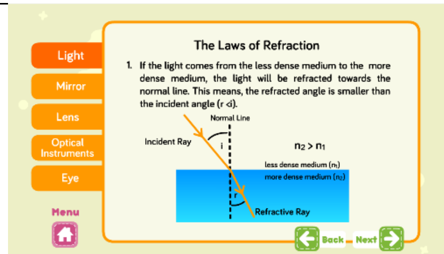
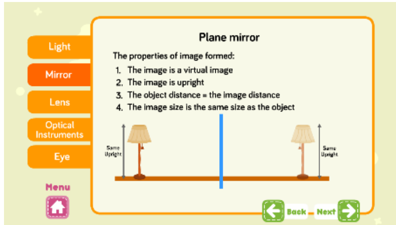


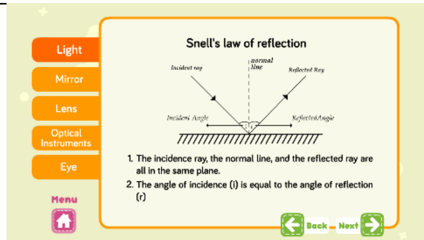
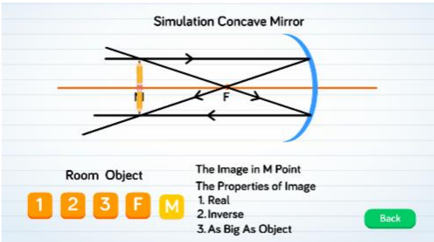
Figure. 5.2. Design of computer simulations using software Adobe Flash Professional CS6

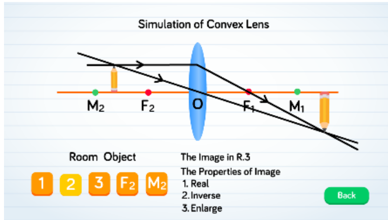
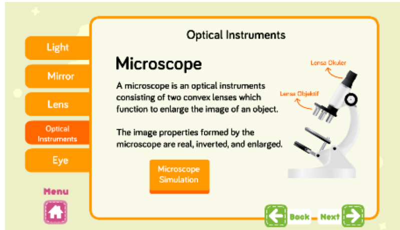
The computer simulations in this research were developed based on the students' misconceptions that were found in the pilot study using TTMCT. The screenshot of computer simulations program to overcome students' misconceptions were provided in Table 5.2. The design phase was to try out the prototype of the computer simulations program to develop the final simulations program for the development phase through the expert assessment to gain comments and suggestions for further improvements.

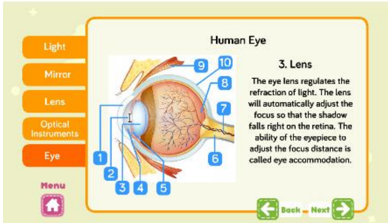
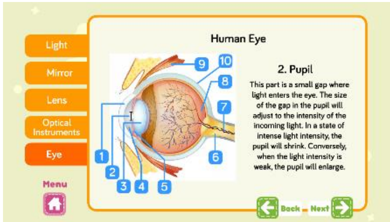
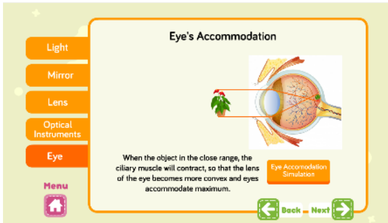
Table 5.2. Overcoming students' misconceptions about light and optical instruments using computer simulations

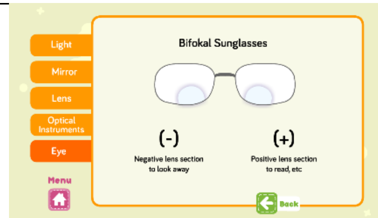
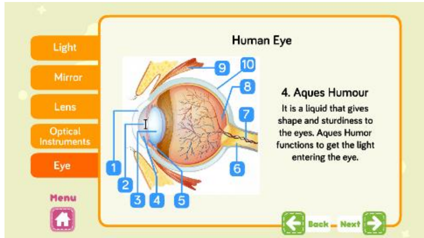
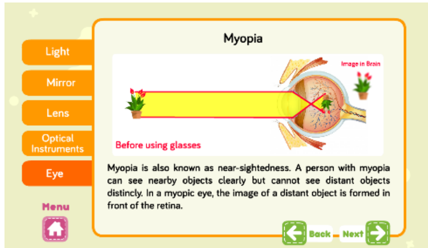
<table>
<tr><th>Students' misconceptions</th><th>Choice combina-tion</th><th>Percentage of student with misconcep-tions</th><th>How simulation overcome students' misconceptions</th><th>Simulation in Program</th></tr>
<tr><td>The properties of light</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Light is an electromagnetic wave and has an infinite speed</td><td>Q1 (A-a)</td><td>23%</td><td>Light is an electromagnetic wave and has a finite speed.
Simulation visualizes light travel with a certain velocity ($3x10^8$ m/s). Sunlight takes an average of 8 minutes and 20 seconds to travel from the Sun to the Earth. In this program, simulations help the students to visualize the phenomenon of light travelling that might be difficult to depict.</td><td>
</td></tr>
<tr><td>A white light bulb is a type of monochromatic lights, and can be broken down into other colors through the process of light diffraction</td><td>Q3 (A-a)</td><td>28%</td><td rowspan="2">A white light bulb is a type of polychromatic lights and can be broken down into other colors through the process of light dispersion.
Simulation shows how white light can be broken down into other colors through the process of light dispersion by using prism glass.
In this program, simulations can animate dynamic process in dispersion process that is difficult to infer from static illustrations that are found in the science textbooks.</td><td rowspan="2">
</td></tr>
<tr><td>A white light bulb is a type of monochromatic lights, and can be broken down into other colors through the process of light dispersion</td><td>Q3 (B-c)</td><td>39%</td></tr>
</table>

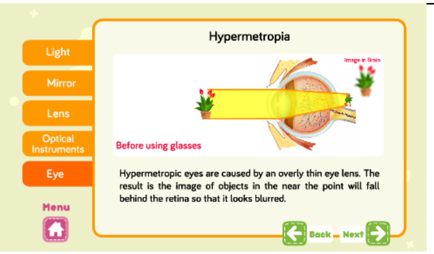
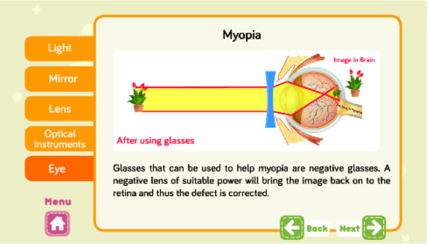
<table>
<tr><th>Students' misconceptions</th><th>Choice combina-tion</th><th>Percentage of student with misconcep-tions</th><th>How simulation overcome students' misconceptions</th><th>Simulation in Program</th></tr>
<tr><td>Light can refract towards the normal when light ray is directly refracted by the rarer medium</td><td>Q4 (B-c)</td><td>25%</td><td>Light can refract towards the normal when light ray goes from a rarer to a denser medium.
Refraction is the bending of the path of a light wave as it passes across the boundary separating two mediums. In this program, simulations help the students to visualize the phenomenon of refraction process between two mediums.</td><td>
</td></tr>
<tr><td>The formation of image on mirrors</td><td></td><td></td><td></td><td></td></tr>
<tr><td>The height of an image is same as the height of the object, while the distance of an image is two times distance of the object</td><td>Q6 (B-a)</td><td>17%</td><td>In plane mirror, the height and distance of the object is equal to the height and distance of the image.
Simulation visualizes the properties of the image formed by a plane mirror, (1) the image is upright, (2) equal to the object in the size, (3) cannot be caught on a screen (virtual image), (4) the distance between the object and the mirror is equal to the distance between the image and the mirror.</td><td>
</td></tr>
</table>

Students' misconceptions	Choice combina-tion	Percentage of student with misconcep-tions	How simulation overcome students' misconceptions	Simulation in Program
The distance of the object affects the magnitude of the incidence and reflection angles	Q7 (B-b)	17%	*The magnitude of reflected angle is influenced by magnitude of incidence angle.* Simulation visualizes the law of refraction process and emphasizes that the magnitude of reflected angle is only influenced by magnitude of incidence angle.	
The magnification of an image is the result of the height of the object with the height of the image	Q12 (A-a)	25%	*The magnification of an image is the result of the distance of the image with the distance of the object.* Simulation can animate ray diagrams in the concave mirror that are difficult to infer from static illustrations found in the textbooks. Simulation illustrates that when the object is located at a position beyond the center of curvature, the image is located at a position between the center of curvature and the focal point. Simulation also illustrates when the object is located between focal length and center of curvature, and between focal length and vertex.	
The magnification of an image is the result of the height of the object with the distance of the image	Q12 (A-b)	16%		

Students' misconceptions	Choice combina-tion	Percentage of student with misconcep-tions	How simulation overcome students' misconceptions	Simulation in Program
Optical instruments				
In a convex lens, if the object position in closer to the lens then characteristics of the image are virtual, upright and enlarge	Q18 (A-a)	21%	*In a convex lens, if the object position is closer to the lens then characteristics of the image are real, inverted, and enlarge.* Simulation helps students to visualize the ray diagrams in convex lens and emphasizes on the image form and properties of images in the convex lens.	
The microscope consists of two convex lenses, the ocular lens (near the object) and the objective lens (near the eye)	Q20 (A-a)	26%	*Microscope consists of two convex lenses: the ocular lens (near the eye) and the objective lens (near the object).* Simulation helps students to visualize the parts of microscope and provide explanations about the function of each part.	
The similarity between human eyes and camera is both of them have concave-convex lens	Q21 (B-d)	17%	*The similarity between human eyes and camera is both have biconvex lens.* Simulation helps students to visualize the parts of human eye, the parts of camera and the similarities of its function.	
The lenses in a camera have a function to controls the accommodating power that has same function with iris in human eye	Q22 (C-a)	24%	*Diaphragm in a camera has a function to control the amount of light into the film.* Simulation helps students to visualize the parts of human eye, the parts of camera and the similarities of its function.	

Students' misconceptions	Choice combina-tion	Percentage of student with misconcep-tions	How simulation overcome students' misconceptions	Simulation in Program
Human Eye				
The eye lens is a part of eye which serves as an image catcher	Q10 (B-b)	19%	*Retina is a part of eye which serves as an image catcher.* Simulation provides clearly information about parts of human eye and its function.	
The eye lens is a part of eye that refracts the light so that it can give the impression of seeing.	Q10 (B-c)	22%		
The pupil is a part of human eye that has a function to focus the light onto the retina	Q11 (C-a)	18%	*The eye lens refracts the light so that it can give the impression of seeing.* Simulation provides clear information about parts of human eye and its function.	
Eye accommodating happens when the object is far, the lens of the eye is flattened, while when the object is close, the muscles in the eye are relaxing and the lens of the eye is bulging	Q19 (D-b)	18%	*Eye accommodating happens when the object is close, the lens of the eye is bulging, while when the object is far, the muscles in the eye are relaxing and the lens is flattening.* Simulation provides animation of human eye that can change optical power to maintain a clear image or focus on an object as its distance varies	
Presbyopia is caused by the cornea is not working properly	Q23 (B-a)	18%	*Presbyopia eye disorder is due to weakening accommodation power.*	

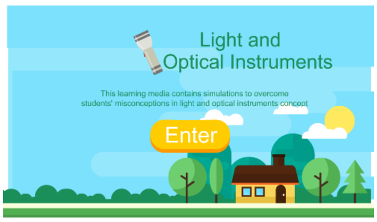
Students' misconceptions	Choice combination	Percentage of student with misconceptions	How simulation overcome students' misconceptions	Simulation in Program
Presbyopia is caused by the pupil is not working properly	Q23 (C-a)	18%	This simulation provides information and picture of how presbyopia happens in the human eye.	
The aqueous humor is located in the iris	Q24 (A-d)	21%	*The aqueous humor is located in the anterior and the posterior chambers of the eye.* Simulation can make abstract science phenomena more accessible and visible to students. Parts of the human eye are abstract for students. Using this simulation, students can directly observe parts of the human eye and its function.	
Eye Disorders				
Myopia can be helped using positive eyeglasses	Q15 (B-a)	16%	*Myopia can be helped using negative eyeglasses.* Simulation can make abstract science phenomena more accessible and visible to students. This simulation provides visualization of how negative eyeglasses can help myopia disorder.	

<table>
<tr><th>Students’ misconceptions</th><th>Choice combina-tion</th><th>Percentage of student with misconcep-tions</th><th>How simulation overcome students’ misconceptions</th><th>Simulation in Program</th></tr>
<tr><td>The characteristic of nearsighted (hypermetropia) is an image formation behind the retina and caused by the shape of the eyeball is too convex</td><td>Q17 (D-b)</td><td>18%</td><td>The characteristic of nearsighted (hypermetropia) is an image formation behind the retina and caused by the shape of the eyeball is too flat.
Simulation provides visualization of human eye optical power changes to maintain a clear image or focus on an object as its distance varies</td><td>
</td></tr>
<tr><td>Myopia can be helped by concave lens which is a positive lens</td><td>Q25 (C-b)</td><td>21%</td><td>Myopia can be helped by concave lens which is a negative lens.
Simulation can make abstract science phenomena more accessible and visible to students. This simulation provides visualization of how negative eyeglasses can help myopia disorder.</td><td>
</td></tr>
</table>

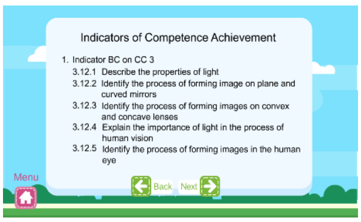
5.4.3. Develop phase

Step 3 was the develop (development) phase. At this phase, the computer simulations about light and optical instruments were produced. This phase included the validation process and revision. Design of the computer simulations in this research contains several parts, such as opening page, competency, material, and evaluation. The opening page shows users that the computer simulations were developed to overcome students' misconceptions in light and optical instrument concepts. The competency part shows the core competency, basic competency, and indicator of competency achievement. The material part is the main parts of the computer simulations. In this part, the concepts of light and optical instruments are divided into five material topics, namely (1) light, (2) mirrors, (3) lens, (4) optical instruments, and (5) Eye.

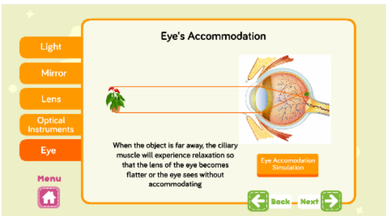
The material part contains summaries and additional materials that students can use to complete the science learning about light and optical instruments. Furthermore, the material also equipped with the simulations that can facilitate students to overcome students' misconceptions and understand the concept of light and optical instruments. For instance, simulation on concave mirror, simulation on a convex mirror, simulation on a concave lens, simulation on a convex lens, and simulation on the human eye. The materials in the simulation were also adjusted with the content of the science curriculum in Indonesia. Finally, the last part is the evaluation part. The students can use the evaluation part to check their understanding of the concepts of light and optical instruments that consist of 20 items multiple choice test questions. The screenshots from computer simulation parts of light and optical instruments concept are shown in Figure 5.3.



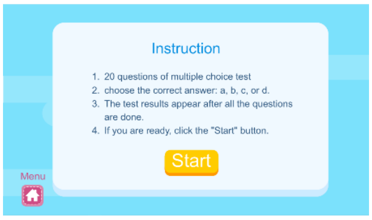
(a) Opening page



(b) Competency



(c) Material



(d) Evaluation

Figure 5.3. Parts of computer simulations about light and optical instrument concepts

The development process of computer simulations also considered the content of light and optical instrument concepts by adjusting the content of the computer simulations and the structure of science curriculum in Indonesia. Based on Indonesian national curriculum, the structure of curriculum consists of organizing of core competency and basic competencies. The core competency for light and instrument concepts is an understanding based on curiosity about science, technology, art, culture-related phenomena and events that can be seen with our eyes (MoEC, 2017). Light and optical instrument concepts consist of five material topics, namely, the properties of light, the formation of images in mirrors, the formation of images in lenses, optical instruments, and the human eye. Details of information about the contents of computer simulations of light and optical instrument concepts are shown in Table 5.3.

Table 5.3. Contents of computer simulations in light and optical instrument concepts

Concept	Material topics	Content of simulations
Light and optical instruments	1. The properties of light	a. Light travel in a straight line b. Light reflection c. Light refraction d. Light is an electromagnetic wave e. Light dispersion
	2. The formation of images in mirrors	a. Images formation in a plane mirror b. Images formation in a concave mirror c. Images formation in a convex mirror
	3. The formation of images in lenses	a. Images formation in a concave lens b. Images formation in a convex lens
	4. Optical instruments	a. Magnifying glass b. Camera c. Microscope d. Periscope
	5. Eye	a. Human eye anatomy b. The process of seeing in the human eye c. Eye accommodation d. Eye disorders

Computer simulations in this study can facilitate students to overcome students' misconceptions and improve students' conceptual understanding of light and optical instruments. For instance, the computer simulations of light, mirror, lens, optical instruments and human eye are shown in Figure 5.4. One misconception in this study was eye accommodation happens when the object is far and the lens of the eye is flattened, while when the object is close, the muscles in the eye are relaxing, and the lens of the eye is bulging. The process of the eye's accommodation is too abstract for students and tends to cause misconceptions. This misconception occurs because the textbooks provide static illustration related to the function of the human eye. Simulation in this study offers the animation and visualization of eye's accommodation that can change optical power to keep a clear image or focus on an object as its distance varies.

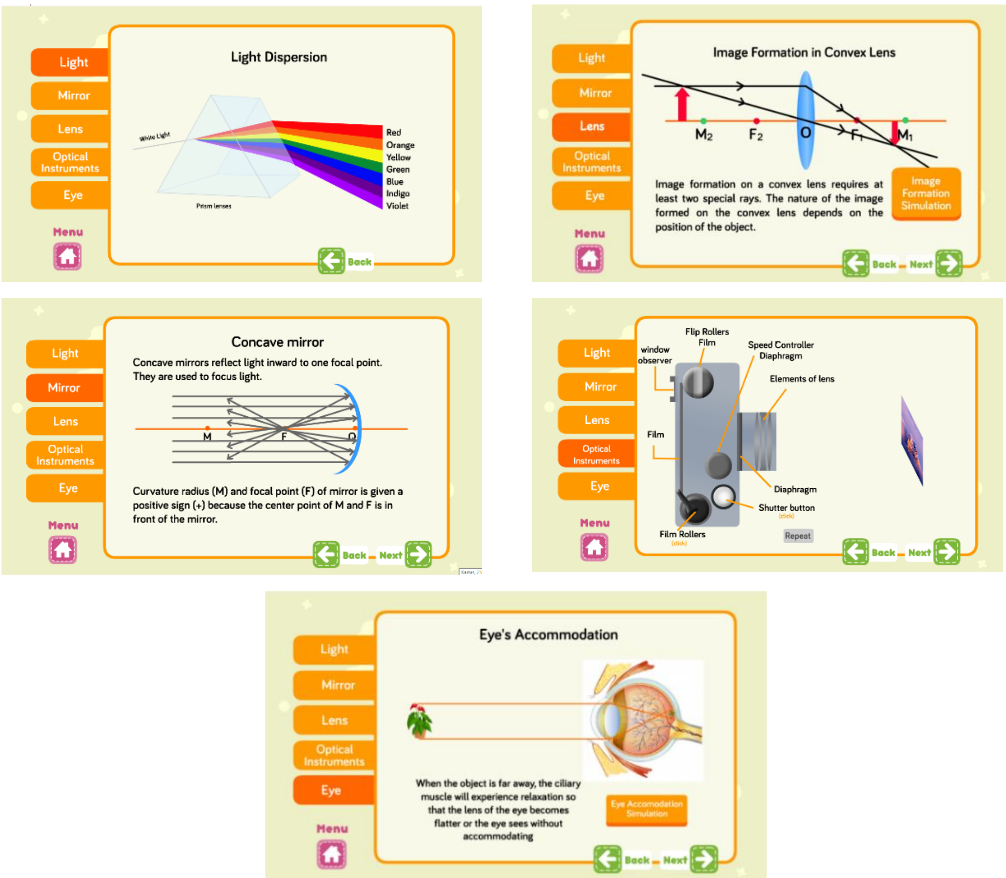


Figure 5.4. Computer simulations of light and optical instrument concepts

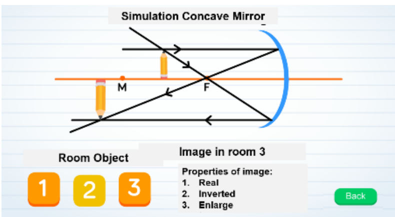
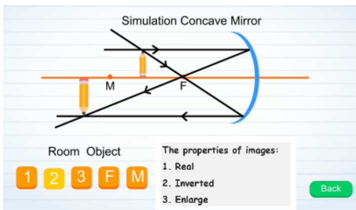
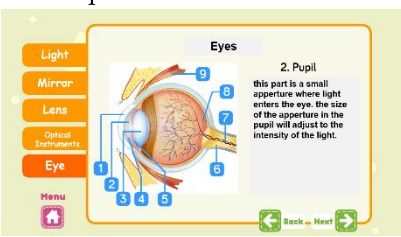
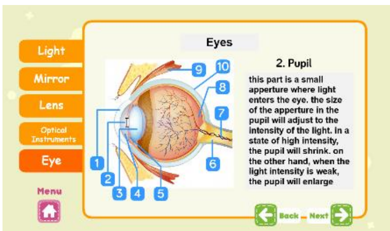
The computer simulations program was reviewed by six science teachers to gain comments and suggestions for further improvement using a set of questionnaires which consisted of 10 item questions with a 5-point Likert scale. The items of the instrument were created to assess simulations from aspects of content explanation and its deepness, display, language use, content, curriculum, and students' misconception. The purposes of this assessment were: (1) to determine whether the simulations are suited with the content in science textbooks or not; (2) to determine the quality of the simulations. To achieve these purposes, the data was collected using a questionnaire. The questionnaires used by science teachers consisted of 10 aspects with 5-point Likert scale. The items of the questionnaire were created to assess simulations from aspects of content explanation and its deepness, display, language use, content, curriculum, and students' misconception. The results of validation by science teachers are shown in Table 5.4.

Table 5.4. Assessment of simulations by science teachers

Aspects	Average percentage	Criteria
Readability of text and writing clearly	90	Very good
The use of simulations can clarify the material	96	Very good
Simulations facilitate conceptual understanding	96	Very good
The display color of simulations is interesting	86	Very good
The language in simulations is easy to understand	96	Very good
The simulations are easy to operate	96	Very good
The depth of concept in simulations is sufficient	96	Very good
The contents of simulations are suitable with curriculum	90	Very good
Simulations are in accordance with learning objectives	90	Very good
Simulations can overcome students' misconception	86	Very good
Average overall simulations assessment	**92**	**Very good**

Table 5.4 shows that the results of the average percentage of the overall simulations assessment. The results of validation by science teachers showed an average overall 92% which indicated that the computer simulations of light and optical instrument concepts in very good criteria and can be used in the learning process. The suggestions from the science teachers about improvements to the computer simulations on light and optical instrument concepts are shown in Table 5.5.

Table 5.5. Improvement of computer simulations based on suggestions from teachers

<table>
<tr><th>No</th><th>Suggestions</th><th>Improvement of computer simulations</th></tr>
<tr><td>1.</td><td>The simulation in the mirror and lens only provides the simulation of image formation in object room 1, 2 and 3. Add the object to the focus point and the center of the mirror.</td><td>Revising the simulation by adding the object in the room 1, 2, 3, focus point and the center of the mirror.</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>2.</td><td>In the human eye anatomy, add information about the pupil. Because it is not a clear picture.</td><td>Revising the simulation by adding the information in the pupil.</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
</table>

5.4.4. Disseminate phase

Step 4 was the disseminate (dissemination) phase. In this phase, computer simulations were disseminated to the three schools in Semarang city, Indonesia. Permission from Education Office of Semarang City was given to conduct research in SMP 6 Semarang, SMP 7 Semarang, and SMP 41 Semarang. Details of the disseminating phase will be discussed in chapter 6.

5.5. Discussion

With the rapid development of information and communication technology (ICT), the use of computer technology in science education has become commonplace (Widiyatmoko, 2018). The using of a computer technology in education is highly recommended by the Indonesian government, as indicated in the National Education System Law No. 20 of 2003. Furthermore, education policy in the Indonesian curriculum mentioned that a computer has the potential to support learning, and it should be used in each subject especially in the science subject.

The use of technology especially computers also contributes to better teaching and learning (Chiu & Wu, 2009). Previous research indicates that digital technology including simulations and animations as effective pedagogical tools that can enhance students' understanding of science concepts, enabling them to integrate modes in visualizing the science concepts (Nakhleh, 1992; Chiu & Wu, 2009). Computer simulations are considered as an effective tool to enhance and improve students' conceptual understanding (Wu et al., 2001; Moore et al., 2014). According to Bell& Smetana (2008), computer simulations are computer-generated dynamic models that present theoretical or simplified models of real-world components, phenomena, or processes. Furthermore, computer simulations are used to model that which are not easily observed in real life (Scalise et al., 2011). By combining animations and visualizing science concepts, the computer simulations can support the development of insight into complex phenomena (Akpan, 2001).

The previous research has been conducted in the science classroom and several advantages of computer simulations are quite compelling. Firstly, simulations can make abstract science phenomena more accessible and visible to students (Muller, Sharma, & Reimann, 2008; Stieff, 2011; Ryoo & Linn, 2012). Secondly, simulations can animate dynamic changes in scientific processes that are difficult to infer from static illustrations found in the textbooks (Marbach-Ad, Rotbain, & Stavy, 2008; Ryoo & Linn, 2012). Thirdly, simulations help students visualize the phenomenon that might otherwise be difficult to depict (Chang, Quintana, & Krajcik, 2010). Fourthly, simulation allows users to experience and interact with an environment similar to the real world (Matveevskii & Gravenstein, 2008; Ruggeroni, 2001). Simulations allow students to play a more active role, thus allowing students to construct their own knowledge. This constructivist approach to teaching and learning is important for overcoming students' misconceptions (Jaakkola, Nurmi, & Veermans, 2011).

The computer simulations of light and optical instruments concept in this study have advantages compared to the others simulations, such as the use of the computer simulation program is very easy; can be used repeatedly without using the internet; the display of simulation is simple and interesting; the simulation can be operated anywhere and anytime according to the need of students; the simulation can overcome students' misconceptions; can improve students' conceptual understanding about light and optical instrument concept, and interactive design that allow students to explore the particular concept of light and optical instruments.

The one unique characteristic of computer simulations is interactivity design. Interactivity enables students to manipulate scientific phenomena. It can show the students the impact of this manipulation as immediate feedback. As a tool for the acquisition of knowledge in an active exploratory learning environment, computer simulations allow students to make interaction activity by clicking the simulation program and answering the questions. During this process, the learner is actively involved in constructing and reconstructing students' knowledge base. The focus within the learning goals thus shifts from recall and reproduction of knowledge to understanding of a domain and transferable knowledge.

5.6. Conclusion

Based on the results and discussions, the computer simulations were developed using 4-D models (define, design, development and disseminate). The reason to develop computer simulations is to overcome students' misconceptions on light and optical instrument concepts. The results of the assessment by science teachers showed an average overall 92% which indicate that the computer simulations about light and optical instrument concept in very good criteria and can be used in the science learning process.

CHAPTER 6
IMPROVING STUDENTS' CONCEPTUAL UNDERSTANDING USING COMPUTER SIMULATIONS ABOUT LIGHT AND OPTICAL INSTRUMENTS

6.1. Overview of the chapter

This chapter discusses the implementation of computer simulations in response to Research Questions 4, which aims to investigate the effectiveness of computer simulations to improve students' conceptual understanding and overcoming students' misconceptions about light and optical instrument concepts. This study is a quantitative method using TTMCT for investigating students' conceptual understanding. For the experimental group (N = 130), the learning process on light and optical instrument concept was taught using computer simulations, and for the control group (N = 134), the same concept was taught using the textbooks. The TTMCT was administered to both the control and experimental group, first in the initial meeting before instructions and second in the seventh meeting after completing the instructions. The learning process was conducted during regular science lessons and conducted twice a week. During the first week, the TTMCT was administered as a pre-test. After completing the instruction for three weeks (on the 7^{th} meeting), the TTMCT was again administered as post-test. For both groups, students' pre-test and post-test responses to the first tier and the combined tiers to each of the 25 items. When the post-test scores were compared by means of the t-test to ascertain the effect of the computer simulations on the students' conceptual understanding, it was found that there was a statistically significant difference between the control and experimental groups [Mexp = 48.61, SDexp = 14.58, Mcon = 36.66, SDcon = 12.7, t = 7.099, sig < 0.05]. The results of this study showed that computer simulations can improve students' conceptual understanding of light and optical instrument concept.

6.2. Introduction

A conceptual understanding is an important cognitive outcome in education especially in the field of science (Renken & Nunez, 2013). Students must be taught to develop a conceptual understanding that is aligned with the conceptual understanding accepted by the scientific community (Ausubel, 1963). Meaningful science learning requires conceptual understanding rather than memorization (Adadan, Trundle, & Irving, 2010). Meaningful learning requires knowledge to be constructed by the learners, not transmitted from the teacher to the students (Jonassen, Peck, & Wilson, 1999). To promote meaningful conceptual understanding, teaching strategies must be found to eliminate misconceptions. Meaningful learning activities helped students to cultivate deep learning and enhance conceptual understanding (Nieswandt, 2007). The conditions that influence the achievement of conceptual understanding applied to the process of learning science as well. Meaningful learning strategies allow students to apply and make sense of what they are learning. As students engage in meaningful learning activities, they are also able to dispel misconceptions.

Studies on students' conceptual understanding of light and optical instruments has attracted the interest of researchers in different countries from early education to university level and beyond (Blizak, Chafiqi, & Kendil, 2015; Heywood, 2005; Kaltakci-Gurel, Eryilmaz, & McDermott, 2016; Tural, 2015; Yalcin, Altun, Turgut, & Aggül, 2009). In science education subject, light and optical instruments are The essential concept of everyday life (Yalcin et al., 2009), and it is used as the primary concept in many science areas ranging from astronomy to zoology (Blizak et al., 2015). It is also an important concept included in the curriculum of many countries, including in Indonesia. However, a literature review on this concept has shown various difficulties in dealing with abstract concepts in the learning process. For instance, Ling (2017) stated that light and optical instruments are complex and difficult concepts. Furthermore, Heywood (2005) stated that students found that the area of light, in particular, is confusing and difficult to understand. Due to the complexity and the difficulty of the concept, students have various misunderstandings and hence have developed misconceptions about this concept (Yalcin et al., 2009). The reasons behind these misconceptions include the instructional methods used (Barke, Hazari, & Yitbarek, 2008), science textbooks (Gudyanga & Madambi, 2014; Kaltakci & Eryilmaz, 2013), teachers' perceptions (Erman, 2017; Satilmis, 2014), and even the students' everyday life experiences (Kaltakci & Eryilmaz, 2013; Widarti, Permanasari, & Mulyani, 2016).

Misconceptions are developed by the students when their understanding of the scientific concept is not in line with the understanding that is being provided by scientists (Allen & Coole, 2012; Barke et al., 2008; Nakhleh & Mitchell, 1993). The previous study mentioned that misconceptions impede the effective learning because the new knowledge cannot be integrated appropriately into students' cognitive structure due to the existing knowledge which is resistant to changes (Ebenezer, Chacko, Kaya, Koya, & Ebenezer, 2010; Taber, 2000). These studies also suggest that in order to develop conceptual understanding, students' misconceptions need modification in a process known as the conceptual change (Chi & Roscoe, 2006; Ebenezer et al., 2010). Previous studies on improving conceptual understanding suggested that the first step towards an effective learning process is to identify the misconceptions and employ effective teaching methods to overcome the misconceptions (Çepni, Taş, & Köse, 2006; Cibik, Diken, & Darcin, 2008).

Overcoming students' misconceptions in science have been explored by previous researchers in the science education field. One strategy is using the teaching method. Research related to misconceptions had shown that traditional teaching methods are not effective for overcoming students' misconceptions (Jimoyiannis & Komis, 2001; Saul & Redish, 1999). One of the teaching methods to overcome students' misconceptions is using computer simulations in the learning process (Chen, Pan, Sung, & Chang, 2013; Moosa, 2015; Ramnarain & Moosa, 2017). A review from previous research on the effectiveness of computer simulations for supporting science learning by Smetana & Bell (2012) stated that computer simulations could help students to eliminate their misconceptions. Computer simulations have the potential to improve conceptual understanding more effectively for abstract scientific concepts, and not easily accessed through direct observations (Zacharia & Olympiou, 2011). Parts of computer simulations that impact students' conceptual understanding can be attributed to the unique affordances that emerge from their multi-representational nature (Olympiou & Zacharia, 2012). For instance, an advantage of computer simulations compared to any other teaching methods is that they involve representations of abstract concept which are invisible in the physical world. As a result, computer simulations provide students through their multi-representational nature which could lead to a deeper conceptual understanding of the scientific phenomena.

Therefore, this chapter aims to investigate the effectiveness of computer simulations to improve students' conceptual understanding and overcome students' misconceptions about light and optical instrument concepts.

6.3. Methods

This study used a quasi-experimental design involving experimental and control groups. This design is suggested as the most appropriate design for measuring the effectiveness of an approach (Creswell, 2012). The sample of this study consisted of 264 junior high school students 8th grade from three public schools in Semarang city, Central Java Province, Indonesia. For this study, the sample was divided into two groups, the experimental and control group. The students have a similar background such as social, cultural and economic background. The average age of students was 13.5 years old (ranging from 13 to 14 years old). For the experimental group (130 students), the learning process of light and optical instrument concepts was taught using the 5M activity and computer simulations, and for the control group (134 students), the same concept was taught using the 5M activity and science textbooks. Students were taught by an expert teacher in teaching science on light and optical instrument concepts. The researchers and the teachers discussed the proper ways of using computer simulations in the classroom. The learning process was conducted during regular science lessons and conducted twice a week. The entire study was completed in four weeks. During the first week, the two-tier multiple-choice tests were administered as a pre-test. After completing the instruction for three weeks (in the seventh meeting), the two-tier multiple-choice tests were again administered as post-test. The research design of this study is shown in Figure 6.1.

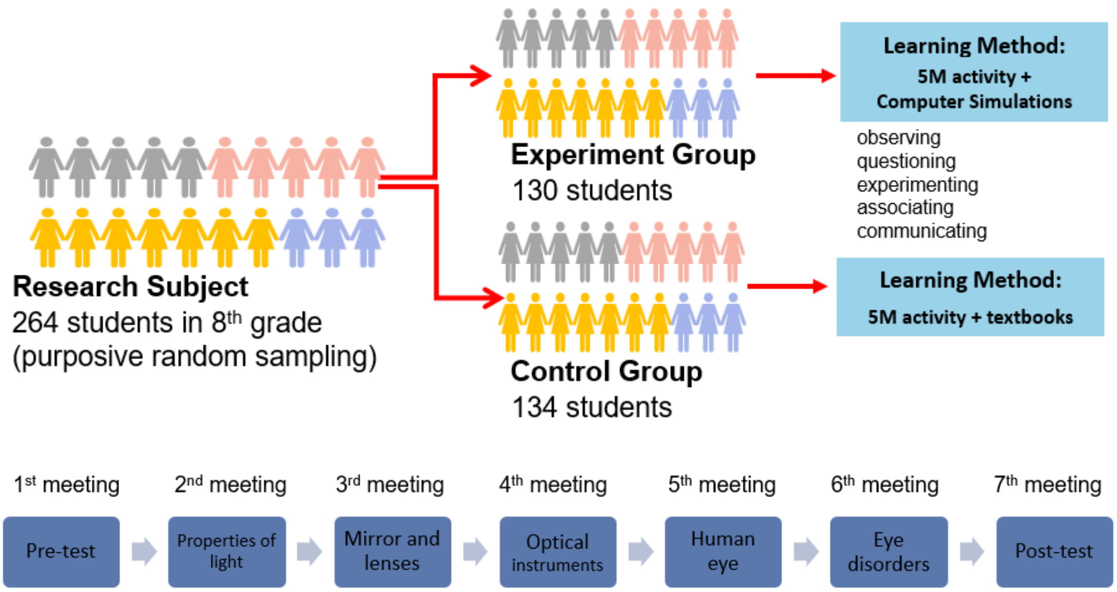


Figure 6.1. Research design.

6.4. Lesson analysis

The lesson analysis presented here, are not intended to describe one single lesson; instead, they depict instruction that typically occurred in lessons conducted in the different classes. The duration was 80 minutes for each lesson. To start the lesson, the teacher asked questions to have students reflect on the concepts and content taught during the previous lesson. This was coded as linking content from one lesson with the previous lesson. Showing the link between lesson content reinforces the concept that caused such a link which leads to a deeper understanding of the concept. The topic of the lesson was introduced with a question, a picture, or a demonstration by the teacher. This usually established a link between the topic and real-life situations. Connections such as these are deemed useful for generating interest in the lesson and for enhancing students' understanding of the related concept.

This study consisted of seven meetings, two meetings were used for the pre-test and post-test, and five meetings were used to teach the concepts of light and optical instruments. Both the experimental and control group were taught the lesson about light and optical instrument concepts by their usual science teacher. Both groups were instructed for an equal amount of instructional time. In total, five lessons were used to teach the concepts of light and optical instruments. The teacher plays the role as a facilitator. Both the control and experiment groups experienced the same teaching and learning process but using different teaching and learning methods.

6.4.1. Experimental group lesson (Example: Lesson 5. Human eye)

In this group, the teacher used computer simulations to teach topic of human eye and eye disorders. In the observing phase, the lesson was introduced to the students by observing the human eye of their friends and tried to analyze the parts of human eye. In the questioning phase, the teacher asked the question "what can you see in your friend's eye?". This question aimed to connect the topic about the human eye and students' prior knowledge. The students try to answer the question from the teacher.

S1: "I see a little black circle in my friend's eye".

S2: "I see a black dot in the center of the eye".

S3: "I see white color in the edge of the eye".

S4: "I see red nerves in the eye".

The students can mention the part of the human eye, but they cannot mention the scientific name of the human eye parts. In order to investigate the scientific name of the human eye, the teacher asks the students to discuss the human eye using the experiment worksheet.

In the experimenting phase, the teacher asked the students to make a group that consists of 4-5 students in each group. The teacher distributed the experiment worksheet to the students about parts of the human eye, each function of the parts of the human eye, and eye disorders. The duration of this phase was 20 minutes. During this activity, the teacher guided the students to fill out the worksheet. Several groups of students did not understand some of the topic in the worksheet. They asked several questions to the teacher: (1) How do our eyes see? (2) What is meant by accommodation of human eye? (3) What is meant by myopia and presbyopia? (4) Why negative lens can help myopia? (5) Why positive lens can help presbyopia? After finishing this phase, the teacher and the students discussed the results in the next phase using computer simulations.

In the associating phase, the teacher and the students discussed the results from the experimenting phase using computer simulations (Figure 6.2). By using computer simulations, the teacher explained the parts of the human eye and each of its function (Figure 6.2a). For instance, in the opening, the students asked questions to the teacher, and in this phase, the teacher answered the questions from the students using interactivity characteristics in the computer simulations. Interactivity in the computer simulations enables the teacher to manipulate scientific phenomena and can show the students the impact of this manipulation as immediate feedback about the parts of the human eye. For instance: (1) the little black circle in the human eye is called iris, (2) the black dot in the center of the eye is called pupil, (3) the white color in the edge of the eye is called sclera, and (4) the red nerve in the eye is called blood vessel. By using computer simulations, the students not only can mention the scientific name of the human eye parts but also can mention the function of each part.

In Figure 6.2b, the teacher explains how the human eye can see the object using computer simulations. When an object is in front of the human eye, this object is considered as a source of light or bounce light. This light enters our eyes with an intensity that is regulated by the pupil and then light is refracted by the eye lens to form a reversed image in the retina. After receiving focused light, the retina transforms this into an electrical impulse, which travels to the brain via the optic nerve. The image we receive on the retina is upside down and our brains turn the image around. Computer simulations provide visual and dynamical unobservable science phenomena about the process of seeing in the human eye.

The teacher showed the simulations of far point and near point of the human eye (Figure 6.2c). The near point of a human eye (25 cm) is the shortest object distance that a typical or "normal" eye can accommodate or form an image onto the retina. The far point of a human eye is the farthest object distance that a typical eye can image onto the retina. It is at infinity for the "normal" eye.

The computer simulations about eye’s accommodation can show in detail what happens in the eye lens (Figure 6.2d). The teacher explained human eye accommodation is the ability of the eye to change its focus from distant to near objects (and vice versa) using computer simulations. When the object is further away, the ciliary muscle relaxes accordingly and increases the tension of the suspensory ligament. As a result, the eye lens becomes thinner, less curved and lesser refractive power to focus the image in the retina. When the object is nearer, the ciliary muscle contracts accordingly and reduces the tension of the suspensory ligament. As a result, the natural elasticity of the eye lens causes it to become thicker, more curved and with higher refractive power to focus the image clearly in the retina. This process is achieved by the lens changing its shape. Computer simulations can make abstract scientific concepts, such as eye's accommodation, more accessible and visible to students.

The next discussion was about human eye disorders. Someone who has trouble seeing distant objects is said to have myopia. In Figure 6.2e, the teacher explains about concept of myopia using computer simulations. Myopia or nearsightedness is eye disorder of vision in which a human eye can see nearby objects distinctly but unable to see distant objects clearly. In the myopia, the image of distant object is formed in front of the retina. This eye disorder can be corrected using a concave lens glasses of suitable focal length. A negative lens of suitable focal length will correct the image back in the retina, so a person can see distant objects clearly. The computer simulations can show how the negative lens working to help the eye disorders.

In Figure 6.2f, the teacher explains about concept of hypermetropia using computer simulations. Hypermetropia or farsightedness is the disorder of vision in which a human eye can see distant objects distinctly but is unable to see nearby objects clearly. In the hypermetropia, the image of nearby objects would fall behind the retina. This eye disorder can be corrected using positive lens glasses of suitable focal length. A positive lens of suitable focal length will correct the image back in the retina, so a person can see nearby objects clearly. The computer simulations can show how the positive lens working to help the eye disorders.

In the computer simulations, the teacher can simulate how a scene might appear to someone with both myopia and presbyopia. Thus, the students will understand the differences between myopia and presbyopia by using computer simulations.

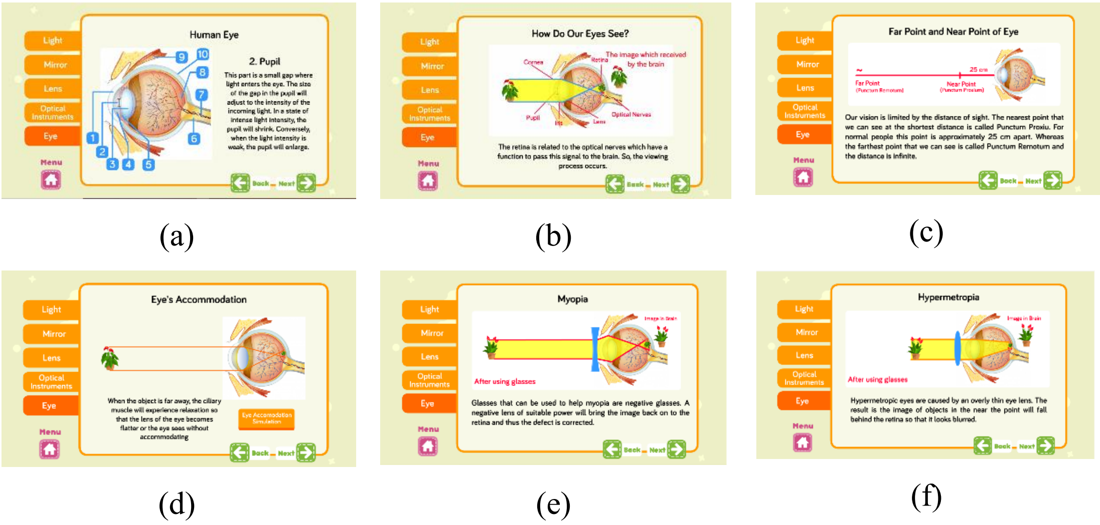


Figure 6.2. Computer simulations of human eye and eye disorders

In the communicating phase, the teacher asked the students to make conclusions about human eye and eye disorders. The students made conclusions about human eye and eye disorders. The teacher checked whether the conclusions were right or wrong. Finally, the teacher wrote the conclusions about human eye and eye disorders in the white board.

6.4.2. Control group lesson (Example: Lesson 5. Human eye)

In this group, the teacher used textbooks to teach topic of human eye and eye disorders. In Indonesia, science textbooks are provided by the MoEC (Ministry of Education and Culture). These textbooks are perhaps the only learning materials available and used in most Indonesian Schools.

In the observing phase, the lesson was introduced to the students by observing the human eye of their friends and tried to analyze the parts of human eye. In the questioning phase, the teacher asked a question "what can you see in your friend's eye?". This question aimed to connect the topic about the human eye and students' prior knowledge. The students try to answer the question from the teacher.

S1: "I see a little black circle in my friend's eye".

S2: "I see a black dot in the center of the eye".

S3: "I see white color in the edge of the eye".

S4: "I see red nerves in the eye".

The students can mention the part of the human eye, but they cannot mention the scientific name of the human eye parts. In order to investigate the scientific name of the human eye, the teacher asked the students to discuss the human eye using the experiment worksheet.

In the experimenting phase, the teacher asked the students to make a group that consists of 4-5 students in each group. The teacher distributed the experiment worksheet to the students about parts of the human eye, each function of the parts of the human eye, and eye disorders. The duration of this phase was 20 minutes. During this activity, the teacher guided the students to fill out the worksheet. Several groups of students did not understand some of the topic in the worksheet. They asked several questions to the teacher: (1) How do our eyes see? (2) What is meant by accommodation of human eye? (3) What is meant by myopia and presbyopia? (4) Why negative lens can help myopia? (5) Why positive lens can help presbyopia? After finishing this phase, the teacher and the students discussed the results in the next phase using science textbooks.

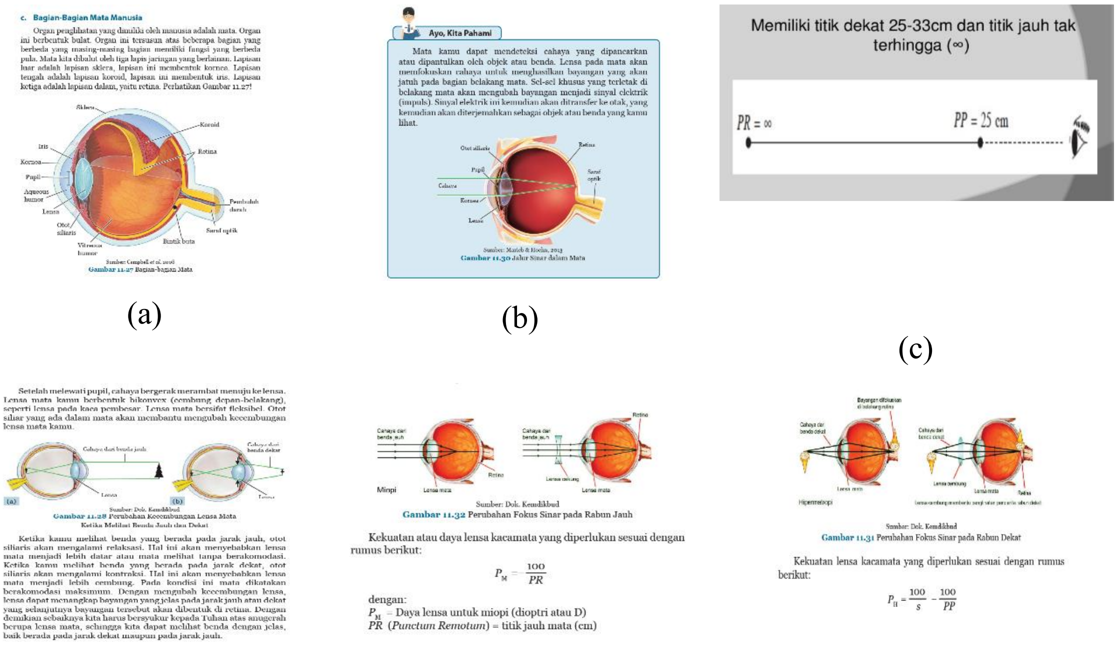
In the associating phase, the teacher and the students discussed the results from the experimenting using science textbooks (Figure 6.3). By using textbooks, the teacher explained the parts of the human eye and each function (Figure 6.3a). For instance: (1) the little black circle in the human eye is called iris, (2) the black dot in the center of the eye is called pupil, (3) the white color in the edge of the eye is called sclera, and (4) the red nerve in the eye is called blood vessel. The textbooks provided a partial explanation of the human eye and each function, namely cornea, iris, eye lens, and retina.

In Figure 6.3b, the teacher explained how the human eye can see the object using textbooks. The teacher explained to the students verbally how our eyes can see. Related to this part, the textbooks provide information that light is very important in the process of seeing.

The teacher explained about far point and near point of human eye (Figure 6.3c). The near point of a human eye (25 to 33 cm) is the shortest object distance that a typical or "normal" eye can accommodate, or to image onto the retina. The far point of a human eye is the farthest object distance that a typical eye can image onto the retina. It is at infinity for the "normal" eye.

The teacher explained about eye’s accommodation in the eye lens (Figure 6.3d). Eye accommodation is the ability of the eye to change its focus from distant to near objects (and vice versa). This process is achieved by the lens changing its shape. Accommodation is the adjustment of the optics of the eye to keep an object in focus on the retina as its distance from the eye varies. By using pictures in the textbooks, the students can see the differences of the shape of eye lens during eye’s accommodation process.

The teacher explained about myopia and hypermetropia. In Figure 6.3e, the teacher explained about the concept of myopia using textbooks. In Figure 6.3f, the teacher explains about the concept of hypermetropia using textbooks. The textbooks provide pictures how the lens working to help the eye disorders. Thus, the students will understand the differences between myopia and presbyopia by using science textbooks.



(a) (b) (c)

(d) (e) (f)

Figure 6.3. Textbooks of human eye and eye disorders

In the communicating phase, the teacher asked the students to make conclusions about human eye and eye disorders. The students made conclusions about human eye and eye disorders. The teacher checked whether the conclusions were right or wrong. Finally, the teacher wrote the conclusions about human eye and eye disorders in the white board.

6.5. Results

The purpose of this study was to investigate the effect of computer simulations to improve students' conceptual understanding and reducing students' misconceptions of light and optical instruments. In the following section, the findings of this research will be presented in three stages, i.e., firstly, analyzed students' responses to items in the pre-test and post-test in the TTMCT; secondly, analyzed the comparison of pre-test and post-test scores in the TTMCT; thirdly, analyzed the percentage of misconceptions identified in the combined tiers or each item.

6.5.1. Analysis of students' responses to items in the pre-test and post-test in the TTMCT

We collected quantitative data for pre-test and post-test of students' conceptual understanding using TTMCT. The TTMCT was administered to both the control and experiment group, once in the first meeting before instruction and again in the seventh meeting after completing the instruction. For both groups, students' pre-test and post-test responses to the first tier and the combined tiers to each of the 25 items were analyzed, and the percentages of correct responses to the items are tabulated in Table 6.1

Table 6.1. Percentage of correct pre-test and post-test responses to the first tier and combined tiers of items in the TTMCT

Questions	Control group				Experiment group			
	Pre-test (%)		Post-test (%)		Pre-test (%)		Post-test (%)	
	First tier	Combined tier	First tier	Combined tier	First tier	Combined tier	First tier	Combined tier
Q1	65	14	80	25	66	24	87	55
Q2	61	42	65	41	66	50	88	71
Q3	8	5	28	26	15	11	71	68
Q4	61	31	70	53	51	27	80	61
Q5	38	10	38	19	42	18	51	36
Q6	60	30	64	46	57	25	75	61
Q7	86	48	83	48	82	42	84	61
Q8	37	26	45	29	48	31	95	75
Q9	25	7	57	55	20	11	79	67
Q10	18	14	31	30	19	14	69	67
Q11	19	8	58	51	14	10	55	51
Q12	66	19	66	30	67	20	65	35
Q13	21	8	53	50	32	13	75	70
Q14	58	25	55	34	48	18	82	60
Q15	30	4	37	14	35	9	82	44
Q16	60	39	74	43	60	40	60	58
Q17	45	20	52	36	49	23	68	55
Q18	26	4	55	10	28	11	39	24
Q19	29	6	64	23	38	15	75	51
Q20	83	52	86	34	84	41	79	59
Q21	46	8	52	13	52	11	69	16
Q22	5	2	26	22	6	5	34	25
Q23	33	20	31	20	35	15	61	50
Q24	29	5	34	22	31	7	44	34
Q25	36	9	42	27	33	5	38	25

The results in Table 6.1 showed that the percentage of correct responses for the first tier was higher than the combined tier for both groups in their pre-test and post-test responses. In the combined tier, the percentage of correct responses in the experimental group was higher than in the control group. Figure 6.4 shows the graphic of comparison percentage correct answer between the control group and the experimental group for answering items in TTMCT in the pre-test and post-test. The experimental group showed better improvement in the post-test compared to the control group, except for item Q11 and Q25. More than 50% of the students in the experimental group managed to answer all questions correctly, except for item Q5 (36%), Q12 (35%), Q15 (44%), Q18 (24%), Q21 (16%), Q22 (25%), Q24 (34%), and Q25 (25%).

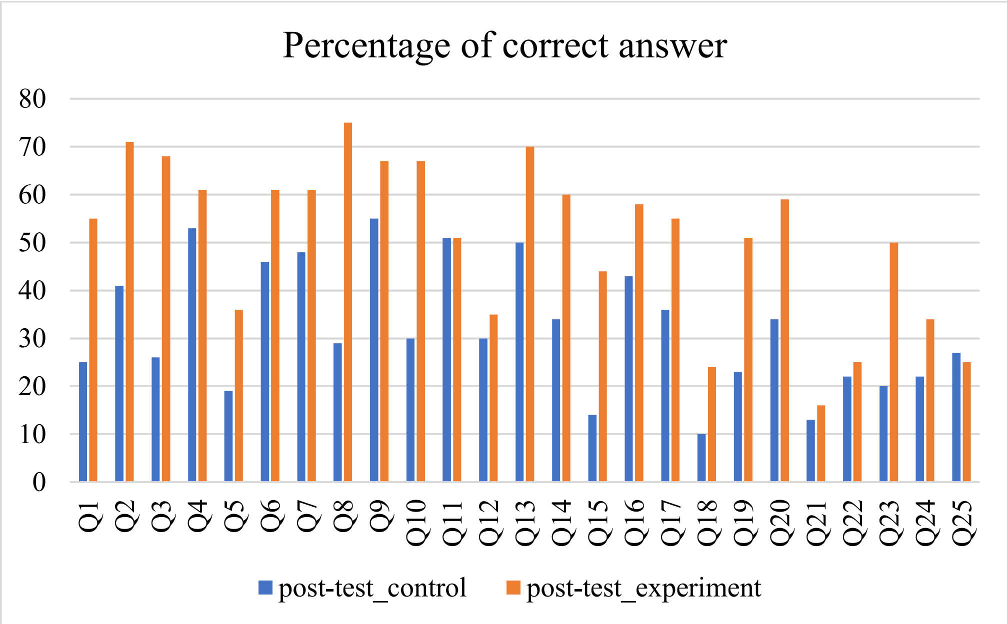


Figure 6.4. Percentage of the correct answer obtained by the control and experimental group in the pre-test and post-test

6.5.2. Pre-test and Post-test Comparisons of Total Scores in the TTMCT

The TTMCT was administered to the students in both the experimental and control groups before the treatment as a pre-test. Independent sample t-test analysis showed no statistically significant differences between pre-test mean scores of the experimental and control groups [Mexp = 28.98, SDexp = 10.96, Mcon = 27.37, SDcon = 6.66, t = 1.448, sig > 0.05] indicating that students in the two groups were similar with respect to the level of their achievement. Means and standard deviations of the TTMCT scores for both groups are given in Table 6.2.

When the post-test scores were compared by means of the t-test to ascertain the effect of the computer simulations on the students' conceptual understanding, it was found that there was a statistically significant difference between the control and experimental groups

[Mexp = 48.61, SDexp = 14.58, Mcon = 36.66, SDcon = 12.7, t = 7.099, sig <0.05]. Comparison of the TTMCT post-test scores of the control and experimental groups are given in Table 6.2. These results showed that students in the experimental group exhibited significantly higher understanding than students in the control group.

Table 6.2. Means and standard deviations for the pre-test and post-test results of TTMCT

Test	Experimental group (N=130)		Control group (N=134)		t	sig. (2-tailed)
	Mean	SD	Mean	SD		
Pre-test	28.98	10.96	27.37	6.66	1.448	0.149
Post-test	48.61	14.58	36.66	12.7	7.099	0.000

An analysis of covariance (ANCOVA) was conducted using pre-test scores as a covariate to determine the differences in post-test mean scores of both groups were significant or not. Based on Table 6.3, the results indicated that the differences were significant ($F(1,261) = 60.620$, $p < 0.05$). The results indicated that conceptual understanding from the experimental group was higher and statistically significant compared to the students in the control group.

Table 6.3. ANCOVA results comparing post-test mean scores of both groups

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	27452.347[a]	2	13726.173	115.950	0.000	0.470
Intercept	6851.692	1	6851.692	57.879	0.000	0.182
Pretest	18039.773	1	18039.773	152.389	0.000	0.369
Group	7176.208	1	7176.208	60.620	0.000	0.188
Error	30897.108	261	118.380			
Total	536220.000	264				
Corrected Total	58349.455	263				

a. R Squared = 0.470 (Adjusted R Squared = 0.466)

6.5.3. Percentage of Students' Misconceptions identified in the combined tiers of each item

One of the purposes of this study was to investigate the effectiveness of computer simulations in reducing students' misconceptions of light and optical instrument concepts. Therefore, the percentage of students' misconceptions in both the pre-test and the post-test were determined using the TTMCT. The misconceptions were grouped under the properties of light, the formation of an image in mirrors and lenses, optical instruments, the human eye, and eye disorders. The results of students' misconceptions are presented in Table 6.4.

Table 6.4. The percentage of students' misconceptions in the pre-test and post-test

Misconceptions	Control group		Experimental group	
	Pre-test (%)	**Post-test (%)**	**Pre-test (%)**	**Post-test (%)**
M1	23	15	23	8
M2	20	11	20	9
M3	33	21	27	8
M4	19	13	18	12
M5	20	14	18	11
M6	25	20	21	12
M7	23	15	15	14
M8	19	13	18	12
M9	31	11	18	7
M10	23	16	24	8
M11	23	17	18	11
M12	25	15	21	8
M13	20	15	18	8
M14	36	26	32	12
M15	23	12	19	8
M16	19	19	18	15
M17	15	11	17	7
M18	17	11	16	8
M19	20	12	17	17
M20	22	12	19	4
M21	17	14	18	11
M22	18	11	18	9

In Table 6.4, the percentages of misconceptions for all 22 items considering all two-tiers for both groups before and after instruction are presented. The percentages of misconceptions differed according to the items. The percentage of misconceptions held by the control group students in the pre-test ranged from 15% to 36% and those for the experimental group ranged from 15% to 32%. In the post-test, the control group students held misconceptions ranged from 11% to 26% and those for the experimental group ranged from 4% to 17%.

Figure 6.5 shows the graphic of comparison percentage students' misconceptions between the control group and the experimental group for answering items in TTMCT in the pre-test and post-test. Based on the results, it is evident that the percentages of students' misconceptions in the experimental group were lower than the control group, except for misconception number 19. This is because the level of complexity of the question is high. Misconception number 19 related to *aqueous humor* which is part of the human eye. This concept is abstract and invisible to students. Thus, students are difficult to understand the parts of the human eye and also its function. Overall, these findings showed that computer simulations used in the experimental group could reduce students' misconceptions about light and optical instrument concepts.

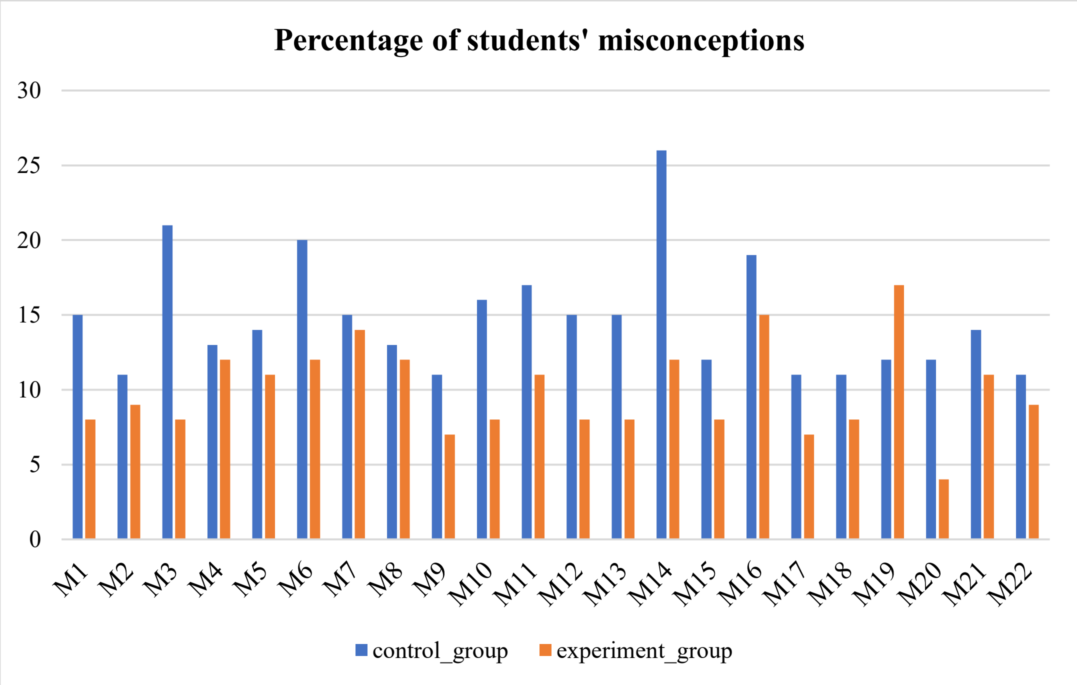


Figure 6.5. Percentage of students' misconception obtained by the control and experimental group in the pre-test and post-test

6.5.3.1. Properties of light

In the pre-test, 23% of students in the control and experimental group believed that *light is an electromagnetic wave and has infinite speed*. This misconception occurs because the students do not have information about the speed of light. Furthermore, students lacked laboratory experiments about these topics. The speed of light is about 300.000 km/s, and students think that light has infinite speed because they taught that the sun is shining every second. The fact is the light needs around 8 minutes 20 seconds to reach on the earth from the sun. As seen in Table 6.4, in both groups, the percentages of misconceptions decreased in the post-test, with 15% in the control group and 8% in the experimental group. The use of computer simulations was the reason for the lower percentage in the experimental group students. This is because the students in the experimental group had visualized the speed of light that occurs too fast in the simulations. Another misconception was that *white light bulb is a type of monochromatic lights and can be broken down into other colors through the process of light diffraction* which held by 20% of students in the control and experimental group in the pre-test. After the treatment, there was a difference between the control and experimental group, but the experimental group (9%) held lower misconceptions than the control group (11%). Apart from that, 33% of the control group and 27% of the experimental group in the pre-test believed that *white light bulb is a type of monochromatic lights and can be broken down into different colors through the process of light dispersion*. In the post-test, the computer simulations successfully reduced the percentage of misconception held by the experimental group, which was only 8% compared to 21% owned by the control group. The students in the experimental group were shown to computer simulations by visualization of white light as the type of polychromatic light that can be broken down into other colors through the process of light dispersion using a prism glass. Computer simulations also can animate a dynamic process in the dispersion process that is difficult to infer from static illustrations found in the science textbooks. Another misconception held was that *light could refract towards the normal when light ray is directly refracted by the rarer medium* which held by 19% of the students in the control group and 18% in the experimental group in the pre-test. After the treatment, the students in the experimental group (12%) performed better than the control group (13%). Refraction is the bending of the path of a light wave as it passes across the boundary separating two mediums. Computer simulations help the students to visualize the phenomenon of refraction process between two different mediums.

6.5.3.2. Formation of an image in mirrors and lenses

Four misconceptions related to the formation of an image in mirrors and lenses were determined. One of the misconceptions identified in this study was *the height of an image is the same as the height of the object, while the distance of an image is two times the distance from the object*. This misconception was held by 20% of the control group and 18% of the experimental group students in the pre-test. After the treatment, the students in the experimental group (11%) performed better than the control group (14%). This is because computer simulations in this study provide visualization the properties of the image formed by a plane mirror, namely (1) the image is upright, (2) equal to the object in the size, (3) cannot be caught on a screen (virtual image), (4) the distance between the object and the mirror is equal to the distance between the image and the mirror. Another misconception was that *the distance of the object affects the magnitude of the incidence and reflection angles* which was held by 25% of the control group and 21% of the experimental group students in the pre-test. The simulations visualized the law of refraction process and emphasized that the magnitude of reflected angle is only influenced by the magnitude of incidence angle. This managed to reduce the misconceptions among the experimental group (12%) students compared to that those in the control group (20%) in the post-test. Apart from that, 23% of the control group and 15% of the experimental group students in the pre-test believed that *the magnification of an image is the result of the height of the object with the height of the image*. After the treatment, the students in the experimental group (14%) performed better than the control group (15%). Another one is *the magnification of an image is the result of the height of the object with the distance of the image* which was held by 19% of the control group and 18% of the experimental group students in the pre-test. Similarly, after the treatment, the students in the experimental group (12%) performed better than the control group (13%). Computer simulations in this study can visualize ray diagrams in the concave mirror that are difficult to infer from static illustrations found in the textbooks. The simulation gives visualization that when the object is located at a position beyond the center of curvature, the image is located at a position between the center of curvature and the focal point. The simulation also gives visualization when the object is located between focal length and center of curvature, and between focal length and the vertex.

6.5.3.3. Optical instruments

Four misconceptions related to optical instruments were determined. One of the misconceptions found in this study was that *in a convex lens, if the object position is closer to the lens then characteristics of the image are virtual, upright and enlarge* was held by 31% of the control group and 18% of the experimental group of students. In this study, simulation helps students to visualize the ray diagrams in the convex lens and emphasized on the image form and properties of the image in the convex lens. In this way, computer simulations were able to reduce the percentage of misconception in the experimental group was only 7% compared to 11% held by the control group. Another misconception, students in both groups thought that *microscope consists of two convex lenses, the ocular lens (near the object) and the objective lens (near the eye)* which was held by 23% of the control group and 24% of the experimental group students. After the treatment, the students in the experimental group (8%) performed better than the control group (16%). This is because simulation helps students to visualize the parts of the microscope and provide an explanation about the function of each component. Apart from that, the students in both groups thought that *the similarity between human eyes and camera is both of them have a concave-convex lens* which was held by 23% of the control group and 18% of the experimental group students. In the post-test, the experimental group (11%) performed better than the control group (17%). Similarly, in the pre-test, 25% of students in the control group and 21% of students in the experimental group believed that *the lenses in a camera have a function to controls the accommodating power that have same function with iris in the human eye*. In the post-test, the experimental group (8%) performed better than the control group (15%). This was because the simulations helped the students to visualize the parts of the human eye and the components of the camera and the similarities of its function. This visualization enabled students to explore the components and its function that difficult to visualize in the textbooks.

6.5.3.4. Human eye and eye disorders

Some of the scientific phenomena in light and optical instrument concepts are abstract and invisible for students, for instance, anatomy and physiology of the human eye. The abstract concept is one of the factors causing students' misconceptions. One of the misconceptions identified in this study was *the eye lens is a part of the eye which serves as an image catcher* was held by 20% of the control group and 18% of the experimental group students. After treatment, the experimental group (8%) performed better than the control group (15%). Another misconception was *the eye lens is a part of the eye that refracts the light so that it can give the impression of seeing* was held by 36% of the control group and 32% of the experimental group students. After treatment, the experimental group (12%) performed better than the control group (26%). Another misconception was that *the pupil is a part of the human eye that has a function to focus the light into the retina* which was held by 23% of the control group and 19% of the experimental group students in the pre-test. After the treatment, the students in the experimental group (8%) performed better than the control group (12%). Another one is *the aqueous humor is located in the iris* was held by 20% of the control group and 17% of the experimental group students in the pre-test. After using computer simulations, the students in the control group (12%) performed better than the experimental group (17%). Computer simulation provides visualization about parts of the human eye and its function. The students can investigate human eye through computer simulations to identify the specific part of the human eye, such as eye lens, pupil, aqueous humor, iris, cornea, sclera, and retina. After using computer simulations, most of the students performed better in the experimental group. However, misconception number 19 related to aqueous humor, the experimental group held higher misconceptions than the control group.

This is because the question in the TTMCT related to aqueous humor was too complex and difficult for the students.

Another misconception identified in this study was that *eye accommodation happens when the object is far away, the lens of the eye is flattened; while when the object is close, the muscles in the eye are relaxing and the lens of the eye is bulging* was held by 19% of the control group and 18% of the experimental group students. In the post-test, computer simulations were able to reduce the percentage of misconceptions from 19% to 15%. Simulation provides animation of human eye accommodation that can change the optical power to maintain a clear image in the retina as its distance varies.

Related to parts of human eye and eye disorder, one misconception identified in this study was *presbyopia is caused by the cornea is not working properly* was held by 15% of the control group and 17% of the experimental group students. After the treatment, the students in the experimental group (7%) were lower than the control group (11%). Another misconception found in this study was *presbyopia is caused by the pupil is not working properly* was held by 17% of the control group and 16% of the experimental group of students. After the treatment, the students in the experimental group (8%) performed better than the control group (11%).

One of the misconception held about eye disorders was *the characteristic of nearsighted (hypermetropia) is an image formation behind the retina and caused by the shape of the eyeball is too convex* which held by 17% of the students in the control group and 18% in the experimental group in the pre-test. Simulations provide visualization of human eye changes optical power to maintain a clear image or focus on an object as its distance varies. Thus, after the treatment the students in the experimental group (11%) performed better than the control group (14%). Apart from that, 22% of the control group and 19% of the experimental group students in the pre-test believed that m*yopia can be helped by using positive eyeglasses*. After the treatment, the students in the experimental group (4%) performed better than the control group (12%). Another misconception was that *myopia can be helped by the concave lens which is a positive lens* which was held by 18% of the control group and the experimental group students in the pre-test. Computer simulation emphasized of how negative eyeglasses can help myopia disorder by refracting the light rays through the negative lens that can make the image to focus at a point in the retina. This manages to reduce the misconceptions among the experimental group (9%) students compared to that in the control group (11%) in the post-test.

6.6. Discussion

This study implemented computer simulations as a tool for improving students' conceptual understanding and overcoming students' misconceptions of light and optical instrument concepts. The computer simulations in this research were developed based on the students' misconceptions that have found in the pilot study using the TTMCT on light and optical instrument concepts. The computer simulations in this research have advantages compared to other simulations, such as the use of the computer simulations program that is very easy; it can be used repeatedly without using the internet; the display of computer simulation is simple and interesting; the computer simulations can be operated anywhere and anytime according to the need of students.

This study answered two research questions. In answering to RQ1 (What is the effect of computer simulations in reducing students' misconceptions about light and optical instrument concepts?), the findings obtained from this study indicated that students in the experimental group showed better conceptual understanding than students in the control group. This finding is shown in Table 6.4. Based on the data analysis, twenty-two misconceptions were identified. Based on the results of this study, the computer simulations were found to overcome students' misconceptions about light and optical instrument concepts. Twenty-two misconceptions were identified and grouped under the headings of 'the properties of light', 'the formation of the image in mirrors and lenses', 'optical instruments', 'human eye and eye disorders'.

Firstly, computer simulations can overcome students' misconceptions about the properties of light. Some of the scientific phenomena in the properties of light happen very fast. For instance, the light speed, light refraction, and dispersion of white light. Computer simulations provide visualization to the students with opportunities to observe specific processes that happen too quickly or too slowly in real life (Akpan, 2001). Furthermore, the simulation that allows zooming and control of speed are even more likely to be facilitated (Tsui & Treagust, 2010). Starting, stopping, and replaying a simulation enable the students to focus on the specific parts and actions that happen too fast.

Secondly, computer simulations can overcome students' misconceptions about the formation of an image in mirrors and lenses. Students' misconceptions related to this topic occurred because the students do not have the mental model on how the image is formed in the mirror or lens. A mental model is like prior knowledge, which influences students' perceptions of phenomena and students' understanding (Buckley, 2000). Computer simulations can help students to generate their mental models and understanding on a new concept (Abdullah & Shariff, 2008; Buckley, 2000; Landriscina, 2009; Nowak, Rychwalska, & Borkowski, 2013; Quellmalz, Timms, Silberglitt, & Buckley, 2012; Treagust, Chittleborough, & Mamiala, 2002). Visualization of phenomena through computer simulations can help students to construct a mental model (Abdullah & Shariff, 2008). The formation of an image in mirrors and lenses topic require students to generate their mental models, and students are aware that physical representations can help them in creating their mental models and understanding on a new concept (Treagust et al., 2002). By using computer simulations, students can see a real situation that helps them to build a mental model. The use of computer simulations can help students to understand science phenomena and mental model constructions. Restructuring students' mental model can help students to increase the conceptual understanding of science concept and overcome misconceptions.

Thirdly, computer simulations can overcome students' misconceptions about optical instruments. Students' misconceptions about optical instruments occurred because the equipment such as a microscope and camera are not available in the classroom. Computer simulations can overcome these misconceptions because it can be used in the class when equipment is not available, or when it is not practical to set it up (Wieman, Adams, Loeblein, & Perkins. K.K., 2010). Computer simulations also allow the students to experience and interact with an environment similar to the real world (Matveevskii & Gravenstein, 2008; Ruggeroni, 2001). In this case, the students can learn about optical instruments such as a microscope and camera using computer simulations in order to achieve conceptual understanding and overcome misconceptions.

Lastly, computer simulations could overcome students' misconceptions about the human eye and eye disorders. Students' misconceptions about this topic occurred because the topic of the human eye and eye disorder is abstract and invisible for the students. From the previous research, computer simulations can make abstract science phenomena more accessible and visible to students (Muller, Sharma, & Reimann, 2008; Ryoo & Linn, 2012; Stieff, 2011). Muller et al. (2008) explained that computer simulations allow learners to represent visually and dynamically essential concepts that would otherwise be invisible. It can provide detailed representations of abstract science phenomena (Ryoo & Linn, 2012; Stieff, 2011), such as eye accommodation, eye disorders, anatomy and physiology of the human eye. It can also animate dynamic changes in scientific processes that are difficult to infer from static illustrations found in the textbooks (Marbach-Ad, Rotbain, & Stavy, 2008;

Ryoo & Linn, 2012). When students are unable to observe abstract science phenomena directly, computer simulations can play a crucial role in helping them understand those phenomena and overcome misconceptions.

On the other hand, there were still some misconceptions that could not be remedied. This is because misconceptions are deeply penetrated into students' minds and resistant to change (Ozmen, 2004; Taber, 2009). Due to time constraints, the use of computer simulations in class discussions was only implemented once for one topic in this study. Thus, some students still resisted to change their misconceptions.

In response to RQ2 (What is the effect of computer simulations in improving students' conceptual understanding of light and optical instrument concepts?), overall results of this study indicated that computer simulations improved students' conceptual understanding of light and optical instruments and had contributed to the greater achievement of the experimental group students. This finding is shown in Table 6.1, Table 6.2, and Table 6.3. Based on the results of this study, it can be concluded that computer simulations are an effective method to improve students' conceptual understanding about light and optical instrument concepts.

The findings in this study are supported by research from previous studies, in which previous studies found that computer simulations had improved students' conceptual understanding in science learning, such as lenses topic (K. E. Chang, Chen, Lin, & Sung, 2008), trajectory motion (Jimoyiannis & Komis, 2001), the electrical circuit (Jaakkola, Nurmi, & Veermans, 2011; Moosa, 2015), mechanics, waves/optics, and thermal physics (Zacharia & Anderson, 2003). They found that students exposed to computer simulations performed better than those taught without computer simulations. This was because computer simulations can support the development of insight into complex phenomena by combining animations and visualizations of abstract science concepts (Akpan, 2001) and make learning abstract concept more concrete (Ramasundaram, Grunwald, Mangeot, Comerford, & Bliss, 2005). Computer simulations can make abstract science phenomena in light and optical instrument concepts more accessible and visible to students.

Computer simulations are used to model phenomena which is not easily observed in real life (Scalise et al., 2011) such as light and optical instrument concepts; for instance, the simulation of eye accommodation. The process of the eye's accommodation is too abstract and not easily observed by the students and tends to cause the misconceptions. Eye's accommodation is the ability of the eye to change its focus from distant to near objects.

According to (Muller et al., 2008; Stephens and Clement, 2015), computer simulations allow students to represent visually and dynamically important concepts that would otherwise be invisible. It can provide detailed representations of unobservable science phenomena (Ryoo & Linn, 2012; Stieff, 2011). It can also animate dynamic changes in scientific processes that are difficult to infer from static illustrations found in the textbooks (Marbach-Ad et al., 2008; Ryoo & Linn, 2012). In particular, computer simulations can help students visualize the phenomenon that might otherwise be difficult to depict (Chang, Quintana, & Krajcik, 2010; Correia, Koehler, Thompson, & Phye, 2019). Therefore, the benefit from computer simulations are making abstract concepts of science more accessible, visible, and can help students to understand science concepts, particularly in light and optical instruments. When students are unable to observe or experience abstract science phenomena directly, computer simulations can play a crucial role in helping them understand those phenomena.

Computer simulations are essential for the learning process in a science subject because it can help students to discover different strategies and helps them to be more active and more engaged in the science learning process leading to meaningful and lifelong learning (Abdoolatiff & Narod, 2009). Furthermore, computer simulations also provided students with environments to exercise reflective thinking processes (Falloon, 2019). However, computer simulations are tools to support science learning. As with another educational tool, the effectiveness of computer simulations is limited by how they are used. Instructional methods proven to promote meaningful learning should be adhered to when using computer simulations. Students should be actively engaged in the acquisition of knowledge and encouraged to take responsibility for their learning.

One of the unique characteristics of computer simulations is interactivity or the potential for interactivity. Interactivity enables students to manipulate scientific phenomena. It can show the students the impact of this manipulation as immediate feedback. This study focused on interactivity between the student and computer simulations program that facilitated students being involved in the learning process. Thus, the students worked on constructing scientific knowledge and concepts by examining their previous knowledge or concepts through manipulating scientific phenomena displayed by the program.

6.7. Conclusion

The purpose of this research was to investigate the effectiveness of computer simulations to improve students' conceptual understanding and overcome the students' misconceptions of light and optical instrument concepts. Based on the results of this study, the computer simulations were found to improve students' conceptual understanding of the light and optical instrument concepts and had contributed to the greater achievement of the experimental group. Furthermore, the findings in this study showed that computer simulations are an effective strategy to improve students' conceptual understanding and overcome their misconceptions about light and optical instrument concepts.

CHAPTER 7
CONCLUSIONS AND IMPLICATIONS

7.1. Overview of the chapter

In the previous chapter, the research data was analyzed and interpreted to address the research questions. Throughout this chapter, relevant conclusions of this research and its implications for the field are discussed. The limitations of the study, the conclusions, and the possibility for future work are presented as well.

7.2. Conclusions of the study

The key focus of this research was to investigate the effectiveness of computer simulations in improving students' conceptual understanding of light and optical instrument concepts and overcoming the students' misconceptions. In order to achieve these aims, a review of the literature on conceptual understanding, misconceptions, computer simulations, light and optical instrument concepts was conducted. This ensured that the researcher was able to address the research questions in this study. The following research questions needed to be addressed are:

1. How to develop a two-tier multiple-choice test to measure students' conceptual understanding and students' misconceptions of light and optical instrument concepts?
2. What are the misconceptions on light and optical instrument concepts held by the students?
3. How to develop computer simulations for improving students' conceptual understanding and overcoming students' misconceptions on light and optical instruments?
4. What is the effectiveness of computer simulations to improve students' conceptual understanding and overcoming students' misconceptions using computer simulations on light and optical instruments?

In order to answer the research questions, this study divided the research into three steps. Step 1 was developing TTMCT about the concepts of "light and optical instruments" for 8^{th} grade to assessed students' conceptual understanding and investigated students' misconceptions. The content area of the TTMCT defined into five topics mentioned in the indicator of competency achievement. They are the properties of light, the formation of images in mirrors, the formation of images in lenses, optical instruments, and the human eye and eye disorders. The TTMCT development procedure had three general steps: defining the content area of the test, identification of students' conceptions, and the development of the test. The final version of TTMCT consisted of 25 question items. Based on the data analysis, twenty-two misconceptions were identified. The results of the study showed that the TTMCT was effective in investigating the students' misconceptions about light and optical instrument concept.

Step 2 was developing computer simulations about light and optical instrument concepts. The computer simulations were developed according to the students' misconception having assessed with TTMCT of light and optical instrument concepts. The computer simulations were developed using software Adobe Flash Professional CS6. Computer simulations in this research were developed by using 4-D model (Define, Design, Develop and Disseminate). Computer simulations were reviewed by six science teachers to gain comments and suggestion for further development using a set of questionnaires which consists of 10 items with 5-point Likert scale. The items of the questionnaires were created to assess computer simulations from aspects of content explanation and its deepness, display, language use, content, curriculum, and students' misconception. The results of the assessment by science teachers showed an average overall 92% which indicate that the computer simulations about light and optical instrument concepts in very good criteria and can be used to overcome students' misconceptions as well as to improve students' conceptual understanding about light and optical instrument concepts.

Step 3 was implementing the computer simulations about light and optical instruments in the 8th grade junior high school students and investigating students' conceptual understanding using TTMCT. This study was a quantitative method using TTMCT for investigating students' conceptual understanding and students' misconceptions. For the experimental group (N = 130), the learning process on light and optical instrument concepts was taught using computer simulations, and for the comparison group (N = 134), the same concept was taught using the traditional method. The TTMCT was administered to both the control and experimental group. During the first week, the TTMCT was administered as a pre-test. After completing the instruction for three weeks (on the 7th meeting), the TTMCT was again administered as post-test. For both groups, students' pre-test and post-test responses to the first tier and the combined tiers to each of the 25 items. When the post-test scores were compared by means of the t-test to ascertain the effect of the computer simulations on the students' conceptual understanding, it was found that there was a statistically significant difference between the comparison and experimental groups [Mexp = 48.61, SDexp = 14.58, Mcon = 36.66, SDcon = 12.7, t = 7.099, sig < 0.05]. Furthermore, an analysis of covariance (ANCOVA) was conducted using pre-test scores as a covariate to determine the differences in post-test mean scores of both groups were significant or not. The results indicated that the differences were significant ($F(1,261) = 118.38$, $p < 0.05$). The results showed that conceptual understanding from the experimental group was higher and statistically significant compared to the students in the control group. Thus, the results of this study showed that computer simulations can improve students' conceptual understanding of light and optical instrument concept.

In order to investigate the effectiveness of computer simulations in reducing students' misconceptions of light and optical instrument concepts, the percentage of students' misconceptions in both the pre-test and the post-test were determined using the TTMCT. Based on the results analysis, it is evident that the percentages of students' misconceptions in the experimental group were lower than the control group. Overall, these findings showed that computer simulations used in the experimental group could reduce students' misconceptions about light and optical instrument concepts.

In conclusion, the computer simulations were found to improve students' conceptual understanding of the light and optical instrument concepts and had contributed to the greater achievement of the experimental group. The findings in this study showed that computer simulation is an effective teaching method to improve students' conceptual understanding and overcome their misconceptions about light and optical instrument concepts.

7.3. Limitations of the study

This study was subjected to some limitations that affected the outcome of the study. Although the findings in this study showed that computer simulations are effective in improving students' conceptual understanding and overcoming students' misconceptions, this study exhibits several limitations.

1. The results and conclusions generated in this study refer specifically to the sample groups involved in the study. Since the investigation involved a small number of participants, the findings in this study may not be generalized to the other contexts.
2. The effects of the students' learning styles, the attitudes of the students towards the learning of science, the classroom climate, as well as the effects of the different

teachers, for example, their content and pedagogical content knowledge, teaching and management styles on the findings are unknown.

3. There are problems associated with the TTMCT. This kind of test is making some demands on the reading or comprehension skill of the respondents (Taber, 1999). Thus, students may not understand or may misinterpret the questions and options in the TTMCT.
4. The results of this test did not form part of the official school assessment. Therefore the students were not taken the test seriously because it did not count for marks. Thus, the results of the test were under-performance of the students in general.

7.4. Implications of the study

Based on the results of this study and findings from the previous studies, following implications can be offered:

1. This study provides evidence that computer simulations are effective method to improve students' conceptual understanding and to overcome students' misconceptions about light and optical instrument concepts. Therefore, it would be advisable to use computer simulations not only for teaching light and optical instrument concepts, but also for all concepts in the science subject in the junior high school level.
2. The results of this study and the previous studies showed that students have misconceptions about light and optical instrument concepts. These misconceptions are resisted to change and obstructing the learning process. The teachers should investigate students' misconceptions. If the teachers know about students' misconceptions, they will be able to provide learning methods in the classroom to overcome the misconceptions.
3. The teachers can use computer simulations about light and optical instrument concepts in the classroom because computer simulations in this research were developed by adjusting the content with the science education curriculum in Indonesia. Furthermore, computer simulations may be used as supplementary tools for classroom instruction and not be used to replace the laboratory activities.
4. The teachers can use the TTMCT for formative evaluation to assess conceptual understanding as well as investigate students' misconceptions of the 8^{th} grade students about light and optical instrument concepts.

7.5. Recommendation for further research

According to the findings and conclusions in this study, the research proposal can be set out for further studies that can help to build upon the results of this study. The recommendations for further studies are:

1. Replication of this study using computer simulations not only for teaching light and optical instrument concepts, but also for all concepts in the science subject in the junior high school level.
2. For this study, only computer simulations were used to improve conceptual understanding. It would be fascinating to investigate what the effects would be if computer simulations were used in conjunction with any kind of technology in order to improve conceptual understanding or other skills in science learning.
3. This study was conducted in three public schools in Semarang city. Further research could be conducted to replicate this study in all public and private schools in Semarang city.
4. The TTMCT was administered to 264 8^{th} grade students. However, the independent variables such as school type, gender, students' learning styles, socio-economic status did not take into this study. Therefore, a study that investigates the effect of these independent variables to the students' conceptual understanding can be studied.

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Appendix 1. Two-Tier Multiple-Choice Test (TTMCT)

Two-Tier Multiple-Choice Test to Assess Students' Conceptual Understanding of Light and Optical Instruments

Subject	: Science
Theme	: Light and Optical Instruments
Level	: Junior High School
Grade	: 8th
Time allocation	: 80 minutes

INSTRUCTIONS

This test consists of 25 questions which measure conceptual understanding about light and optical instruments. Each question has two parts: a multiple choice reponse and a multiple choice reason. You are asked to make one choice from both multiple choice response and one choice from the multiple choice reason for each question.

Answer all questions on the answer sheet.

1. Write your identity on the answer sheet.
2. Read each question carefully.
3. Take time to consider your answer and carefully select a reason which best represent your understanding.
4. Write your answer by placing an "X" over the letters which match your answer and your reason on the answer sheet.

   e.g. ~~A~~ X B C D

5. If you change your mind about an answer, cross out the old answer and add the new choice as shown.

   e.g. ~~X~~ B ~~C~~ X D

6. Don't forget to record your answer on your answer sheet.

Read the following section and answer the questions number 1 to5!

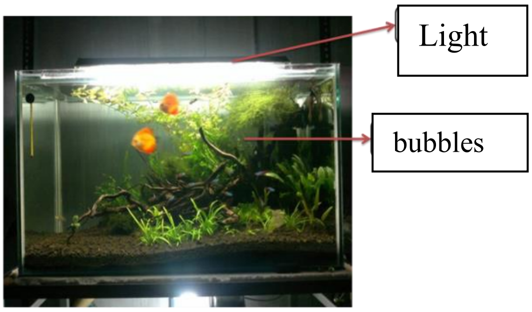


Figure 1. Fish in the aquarium

Novi has an empty aquarium box. When she fills the aquarium, it turns out the aquarium base looks more shallow. After that, she fills the aquarium with fish and aquatic plants, and puts a white halogen lamp on top of the aquarium. When the light is on, the aquatic plants produce the air bubbles. When the lights is off, the air bubbles are not generates (Figure 1).

1. Which is the definiton of light?
   A. Light is an electromagnetic wave
   B. Light is a mechanical wave
   C. Light travels unlimited distance
   D. light is a longitudinal wave
   Reason:
   a. Light has an infinite speed
   b. Light can travel through a vacuum
   c. Light can pass through all object
   d. Light can propagate if there is a medium

Indicator CU: Generate or explain definitions of single concepts

2. We can see the fish in the aquarium. The fact about the relationship between light and the ability of the eye to see objects is ....
   A. The eye can see objects because the object can absorb the received light
   B. The eye can see objects because the objects reflected light, so that light enters the eye
   C. The eye can see objects because the object refracted light, so that light enters the eye
   D. The eye can see objects because the eye nerves can see objects, so the ability of the eye to see the object has no relationship with light
   Reason:
   a. Eyes can see even without light
   b. Eyes can produce light, so the eyes can see objects
   c. Light coming from a light source directly enters to our eyes
   d. If there is no light to reflect at an object, no object can be seen

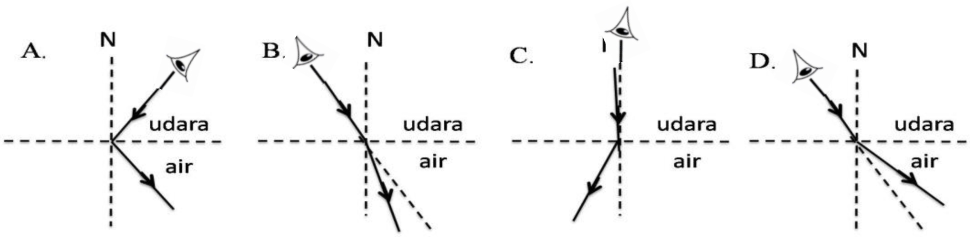
Indicator CU : Recognize relationships among the concepts

3. The white light bulb is a type of ... light, which can be broken down into the colors of its forming light through the process of ....
   A. monochromatic; diffraction of light
   B. monochromatic; dispersion of light
   C. polychromatic; diffraction of light
   D. polychromatic; dispersion of light

   Reason:
   a. white light bulbs can be broken down into other colors through the process of light diffraction for the photosynthesis process
   b. white light is a single light that can directly affect the process of photosynthesis
   c. white light can be broken down into the colors of its forming light through the process of light dispersion for the photosynthesis process
   d. white light cannot be broken down, because it is the base color

Indicator CU : Give examples of the concept

4. Novi saw the bottom of the aquarium looks shallow. The direction of the correct refractive ray corresponding to the events experienced by Novi is shown by image....(B)



   Reason:
   a. Light ray goes from rarer to denser medium.
   b. Light ray goes from denser to rarer medium.
   c. Light ray directly refracted by rarer medium
   d. Light ray is not refracted but are passed on the medium

Indicator CU: communicate learning outcome from the result of conceptual change

5. Light belongs to the ... wave.
   A. radio
   B. longitudinal
   C. transversal
   D. mecanic

   Reason:
   a. There is no correlation between the direction of the electric field vibration and the magnetic field in determining the type of light waves
   b. The direction of the electric field and magnetic field vibration perpendicular to the direction of propagation.
   c. The direction of the electric field vibration and its magnetic field parallel to the direction of its propagation.
   d. Only one of the magnetic fields and electric fields affect the direction of the light wave vibration.

Indicator CU: Define the concept

Read the following section and answer the questions number 6 to 7!

Look at the picture below!

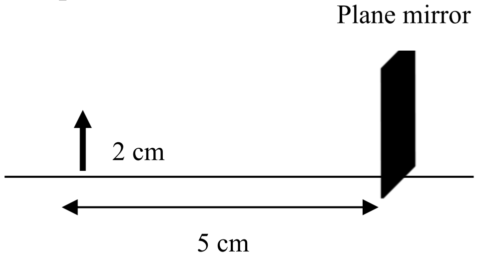


Figure 2. Image formation in a plane mirror

6. Based on Figure 2, the height and distance of the image from the mirror is ....
   A. 5 cm and 2 cm
   B. 2 cm and 10 cm
   C. 7 cm and 10 cm
   D. 2 cm and 5 cm

   Reason:

   a. The height of the image is the same as the height of the object, while the distance of the image two times the distance of the object
   b. The distance of the image is calculated from the distance of the object, the height of the image remains the same.
   c. The height and distance of the object is equal to the height and distance of the image
   d. The height of the image and the distance of the image is not the same as the height of the object and the distance of the object to the mirror.

Indicator CU: Recognize relationships among the concepts

7. Data obtained in the measurement of incidence angle and reflected angle in a plane mirror:

No.	Distance of object (cm)	Angle of incidence (°)	Angle of reflection (°)
1	25	25	25
2	20	30	30
3	15	35	35
4	10	45	45

   From the data in the table, the conclusion of the measurement is ....
   A. Angle of incidence ≠ angle of reflection
   B. Angle of incidence = angle of reflection
   C. Angle of incidence = distance of object
   D. Angle of incidence ≠ distance of object

   Reason:

   a. The magnitude of incidence angle different with the reflected angle
   b. Distance of the object affects the magnitude of the incidence angle and reflection angle
   c. The magitude of incidence angle not related with magitude of reflected angle
   d. The magnitude of reflected angle influenced by magnitude of incidence angle

Indicator CU: Construct their own knowledge through exploring their experiences

8. When a ray of light strikes a plane mirror in the direction perpendicular to the surface of the mirror, the reflection angle is ....
   A. 0^o
   B. 45^o
   C. 60^o
   D. 90^o
   Reason:
   a. The reflection angle is the angle between the reflected ray with the mirror surface
   b. The reflection angle is the angle between the reflected ray with the normal line
   c. The reflection angle is not the same as the incident angle
   d. The reflection angle can not be determined

Indicator CU: Recognize relationships among the concepts

9. The number of images formed two plan mirrors with forming the angle 60° is ....
   A. 4
   B. 5
   C. 7
   D. 8
   Reason:
   a. The number of image formed is 360° divided by the angle between the two mirrors then added with one
   b. The number of image formed is 360° divided by the angle between two mirrors then reduced by two
   c. The number of image formed is 360° divided by the angle between the two mirrors then reduced by one
   d. The number of image formed is 360° divided by the angle between two mirrors then added by two

Indicator CU: Represent a concept in different ways and identify the connections among these representations.

See Figure 3 and Figure 4 to answer the questions number 10 to 12!

Figure 3. Formation of image in a mirror

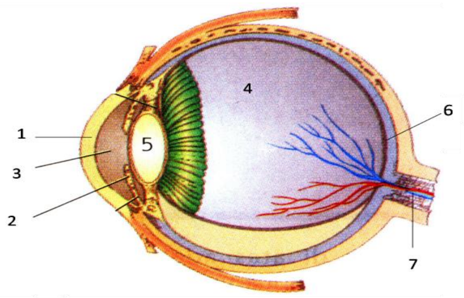


Figure 4. Part of the human eye

10. In figure 3, the screen serves as an image catch of the objects. In figure 4, the part of the human eye which serves as an image catcher formed by the lens of the eye, indicated by number ....

A. 1 C. 6

B. 5 D. 7

Reason:

a. That part is cornea that is directly related to light.
b. That part is the retina is directly related to the optic nerve.
c. That part is the lens of the eye that reflects the light so that it can give the impression of seeing.
d. That part is the optic nerve, which continues the image to the brain.

Indicator CU: Represent a concept in different ways and identify the connections among these representations.

11. Based on figure 4, if the lenses in the experiment as image former look clearer. Thus, part of the eye as a shaper and image former in the retina showed by number ....

A. 1 C. 3

B. 6 D. 5

Reason:

a. That part is a cornea that is directly related to light.
b. That part is the retina is directly related to the optic nerve.
c. That part is the lens of the eye that refracts the light so that it can give the impression of seeing.
d. That part is the optic nerve, which continues the image to the brain.

Indicator CU: Represent a concept in different ways and identify the connections among these representations.

12. An object with a height of 5 cm is placed in front of a concave mirror and obtained an image with height 15 cm and a distance of 30 cm, the magnification of the image and the distance of the object to the mirror is ....

A. 3 times and 10 cm
B. 3 times and 3 cm
C. 5 times and 10 cm
D. 5 times and 3 cm

Reason:

The magnification of the image is the result of:

a. The height of the object with the height of the image
b. The height of the object with the distance of the object
c. The height of the image with the distance of the image
d. The distance of the image with the distance of the object

Indicator CU: Solve problems to new situations by applying acquired knowledge, facts, techniques and rules in a different way

13. Look at the following table!

No	experiment result	
	s (cm)	**s' (cm)**
1	20	20
2	15	30
3	60	12

From the experimental results using a concave mirror in the table above, then the focal distance of the mirror is ....

A. 5 cm
B. 10 cm
C. 15 cm
D. 20 cm

Reason : Relationship among the object distance (s) dan image distance (s') dan focal length (f) in a concave mirror is :

a. $\frac{1}{s}+\frac{1}{s'}=\frac{1}{f}$

c. $\frac{1}{s}+\frac{1}{f}=\frac{1}{s'}$

b. $\frac{1}{s}-\frac{1}{s'}=\frac{1}{f}$

d. $\frac{1}{s'}-\frac{1}{s}=\frac{1}{f}$

Indicator CU: Construct students' knowledge through exploring their experiences

Read the following section and answer the questions number 14 to 16!

Resti is a grade VIII student. She is looking at posters on school walls. She can not see clearly the posters that are within 100 cm, whereas her friend can clearly read the article on the poster.

14. Based on the text above, Resti has eye disorder ....

A. emmetrope
C. myopia
B. hypermetropia
D. presbyopia

Reason:

a. The eyeball shape is too convex but can be flattened, so the image falls on the retina
b. The shape of the eyeball is too flattened so that the image falls behind the retina so it cannot see a close distance
c. The shape of the eyeball is flat, causing the image to fall in front of the retina so that it cannot see the close distance
d. The shape of the eyeball is too convex and cannot be flattened, consequently the image of the object falls in front of the retina

Indicator CU: Interpret new knowledge based on prior knowledge

15. Based on the text, Resti should use eyeglasses with optical power...

A. – 1 dioptre
C. - $\frac{1}{2}$ dioptre
B. + 1 dioptre
D. + $\frac{1}{2}$ dioptre

Reason:

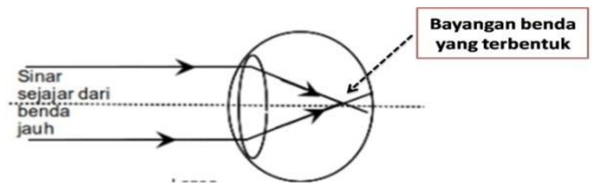
The optical power for Resti eyeglasses influenced by:

a. Punctum remotum
b. Punctum proximum
c. Normal reading distance
d. Eye focus distance

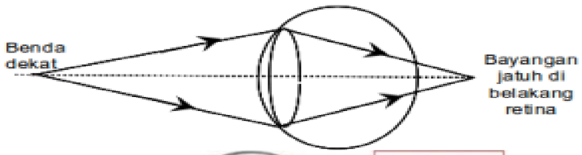
Indicator CU: Apply science to real-life and other situations.

16. Hypermetropia eye disorder are shown by images....(B)

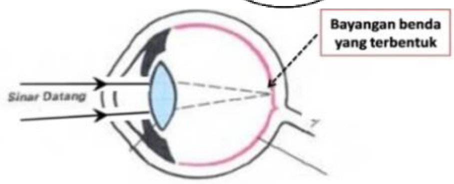
A.



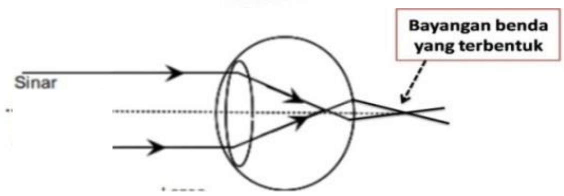
B.



C.



D.



Reason:

a. The shape of the eyeball is too convex and cannot be flattened, consequently the image of the object falls in front of the retina
b. The eyeball shape is too convex, but can be flattened, so the image falls on the retina
c. The shape of the eyeball is too flattened so that the image falls behind the retina so it cannot see a close distance.
d. The shape of the eyeball is flat, causing the image to fall in front of the retina so that it cannot see the close distance

Indicator CU: Compile knowledge together in a different way by combining in a new pattern

Read the following section and answer the questions number 17!

An owl has one part of the eye called *Tapetum lucidum* in the retina. The function of *Tapetum lucidum* is to improves eyesight on weak light conditions and helps to hunt at night. The human eye has no *Tapetum lucidum* layer, so humans need light to see things around them. However, although owls have *Tapetum lucidum*, owls are nearsighted, so they can not see clearly the objects around them when they are too close (Wikipedia, 2017).

17. Based on the text, it is known that owls are nearsighted. The characteristics of eyes that are nearsighted is ....
    A. Formed image in the retina
    B. Formed image in front of the retina
    C. Formed image between retina and sclera
    D. Formed image in the behind of the retina
    Reason:
    a. The shape of the eyeball is too flat
    b. The shape of the eyeball is too convex
    c. The shape of the eyeball is normal
    d. The shape of the eyeball are flat and convex

Indicator CU: Generate or explain definitions of single concepts

18. Look at the picture below!

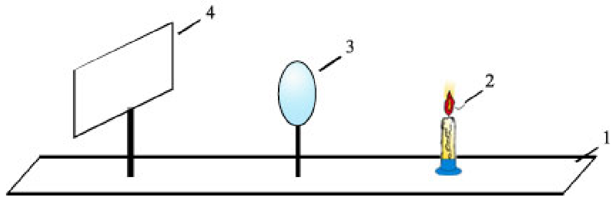


Figure 5. Image formation in convex lens

If a 10 cm candle is placed 20 cm in front of the convex lens, and the focal length of the lens is 15 cm, the distance of image and its characteristics are....
    A. 30 cm; characteristics: virtual, upright, larger than the object
    B. 30 cm; characteristics: real, upright, infinite image
    C. 60 cm; characteristics: real, inverted, larger than the object
    D. 60 cm; characteristics: real, inverted, smaller than the object
    Reason:
    a. The object is located closer to the lens than the focal length of the convex lens
    b. The object located just as long as the focal length of the convex lens
    c. The distance of the object is bigger than the radius of curvature of the convex lens
    d. The object is located between the focus of the lens and the radius of the lens curvature

Indicator CU: Apply science to real-life and other situations.

Read the following section and answer the questions number 19 to 22!

Optical Instruments

Optical instruments are tools which components use optical objects, such as mirrors, lenses, optical fibers or prisms. The working principle of optical instruments is to utilize the principle of light reflection and refraction of light. Optical instruments include eyes, cameras, microscopes, loops, and telescopes.

A camera is an optical instrument for recording or capturing images. The images may be individual photographs or sequences of images constituting videos or movies. The word camera comes from camera obscura, which means "dark chamber" and is the latin name of the original device for projecting an image of external reality onto a flat surface. The modern photographic camera evolved from the camera obscura. The functioning of the camera is very similar to the functioning of the human eye. The first permanent photographof a camera image was made in 1826 by Joseph Nicéphore Niépce.

19. Look at the following picture!

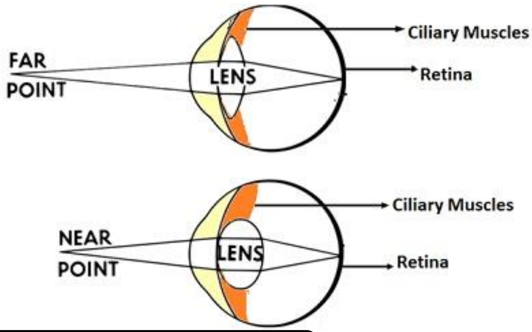


Figure 6. Human Eye

The figure shows that the human eye is able to ...

A. bulging
B. flattening
C. adapt
D. accommodating

Reason:

a. when the object is close the lens of the eye is flattened, while when the object is far the muscles in the eye contracting and the lens is flattening
b. when the object is far the lens of the eye is flattened, while when the object is close the muscle in the eye relaxing and the lens of the eye is bulging
c. when the object is close the lens of the eye is bulging, while the object is far the muscles in the eye relaxing and the lens is flattening
d. when the object is far the lens of the eye is bulging, while the object is close the muscles in the eye contracting and the eye lens is bulging

Indicator CU: Construct students' knowledge through exploring their experiences

20. Optical instrument that consist of two lenses and the function is to see objects very small become bigger and clearer is ....

A. Microscope
B. Telescope
C. Magnifying glass
D. Binocular

Reason:

a. This optical instrument consists of two convex lenses: the ocular lens (near the object) and the objective lens (near the eye).
b. This optical instrument consists of two convex lenses: the ocular lens (near the eye) and the objective lens (near the object).

c. This optical instrument consists of two concave lenses: the ocular lens (near the object) and the objective lens (near the eye).
d. This optical instrument consists of two concave lenses: the ocular lens (near the eye) and the objective lens (near the object).

Indicator CU: Apply science to real-life and other situations.

21. Look at the figure 7 and 8!

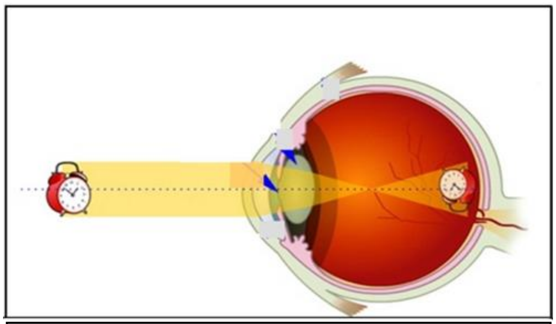


Figure 7. Forming image in human eye

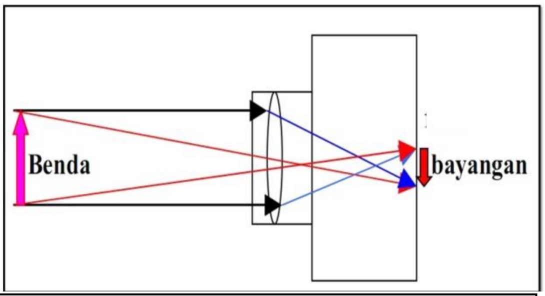


Figure 8. forming image in the camera

Based on Figure 7 and 8, the similarities between the eyes and the camera shown in the image is ....
A. real, inverted, enlarged
B. real, inverted, diminished
C. virtual, inverted, enlarged
D. virtual, inverted, diminished

Reason:
a. both of them have biconvex lenses
b. both of them have biconcave lenses
c. both of them have bifocal lenses
d. both of them have concave-convex lenses

Indicator CU : Interpret new knowledge based on prior knowledge

22. Part of the camera that works the same as the iris on the eye is ....
A. diapraghm C. lens
B. aperture D. film

Reason:
The function of that part is:
a. controls the accommodating power
b. controls the amount of light in to the film
c. forward the light
d. Protect the eyes from excessive light

Indicator CU: Apply science to real-life and other situations.

Look at the figure 9 to answer questions number 23 to 25!

23. Based on Figure 9, eye disorder presbyopia because of the eye part number ... is not working properly.
    A. 1
    B. 3
    C. 4
    D. 5

    Reason:

    a. Presbyopia eye disorder due to weakening accommodation power
    b. Presbyopia eye disorder due to the lens is too convex
    c. A dirty cornea causes a person suffering presbyopia
    d. Corneas that are unable to accommodate are the main causes of presbyopia

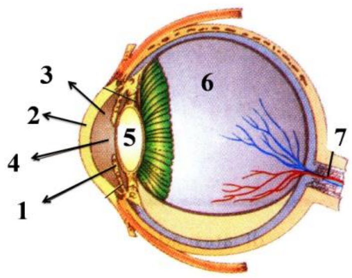


Figure 9. Part of the eye

Indicator CU : Compile knowledge together in a different way by combining in a new pattern

24. Based on Figure 9, guess this riddle! I am a clear liquid, located behind the cornea of the eye, and the function is to refract light into the eye. The location of the clear liquid is indicated by number ....
    A. 1
    B. 2
    C. 3
    D. 6

    Reason: The liquid is…

    a. Human tears
    b. vitreous humor
    c. plasma liquid
    d. aqueous humor

Indicator CU : Recognize relationships among the concepts

25. Person who has eye's disorder is myopia, can be helped by lens....
    A. Bifokal
    B. Convex
    C. Concave
    D. Concave and convex

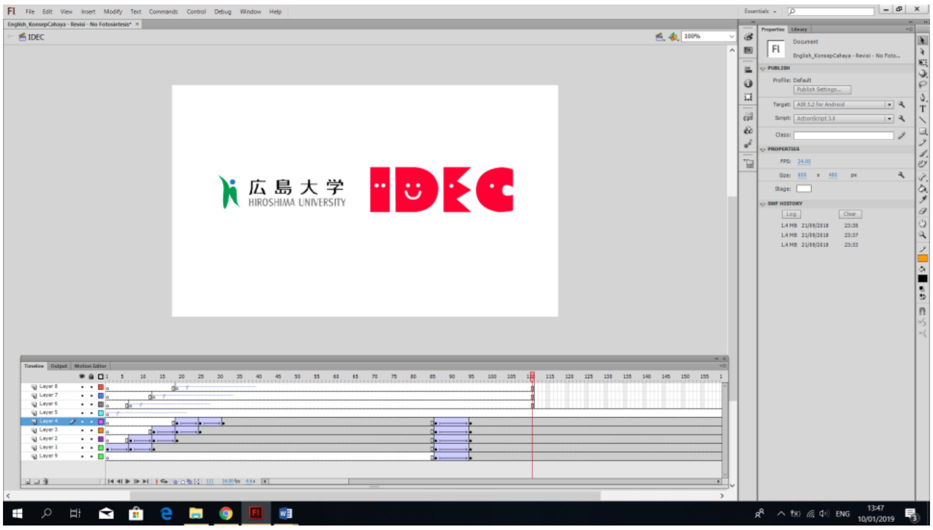
    Reason:

    a. The type of lens is negative, so the image that initially falls in front of the retina can fall on the retina
    b. The type of lens is positive, so the image that initially falls in front of the retina can falls on the retina
    c. The type of lens is negative, so the image that initially falls behind the retina can falls on the retina
    d. The type of lens is positive, so the image that initially falls behind the retina can falls on the retina

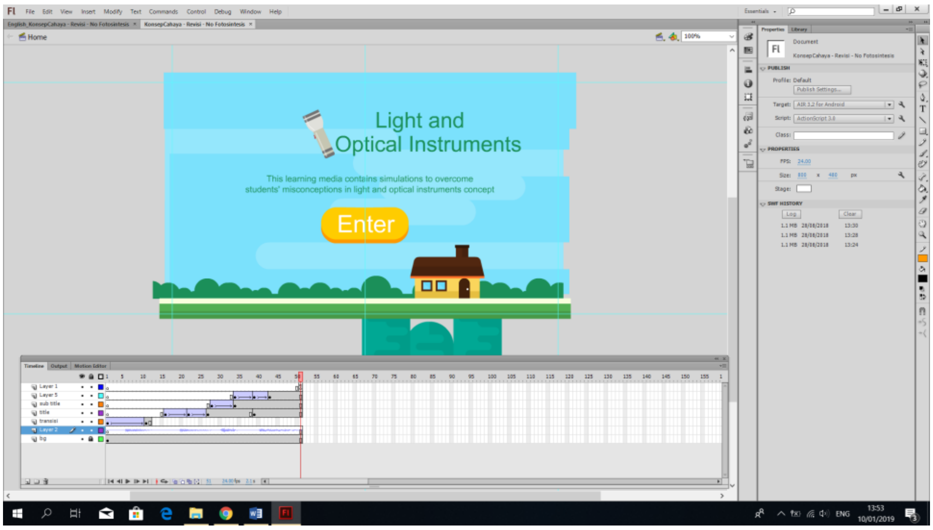
Indicator CU: Recognize that learning result is meaningful and make sense.

Appendix 2. Screen Shoot of Computer Simulations Program Using Adobe CS6

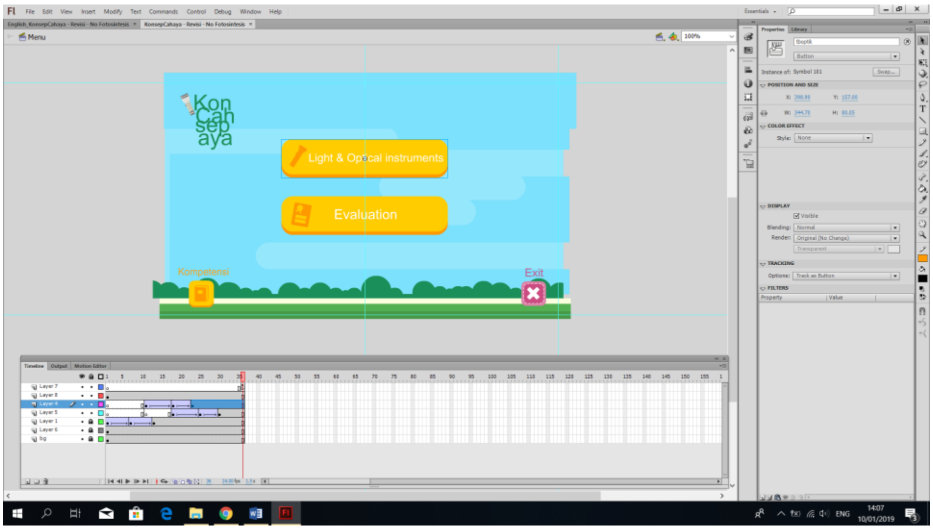
1. Opening



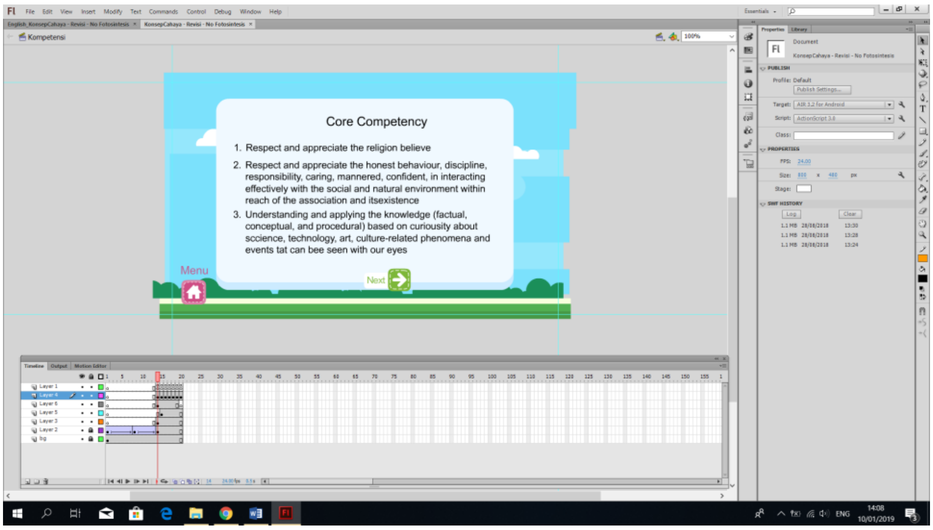
2. Home



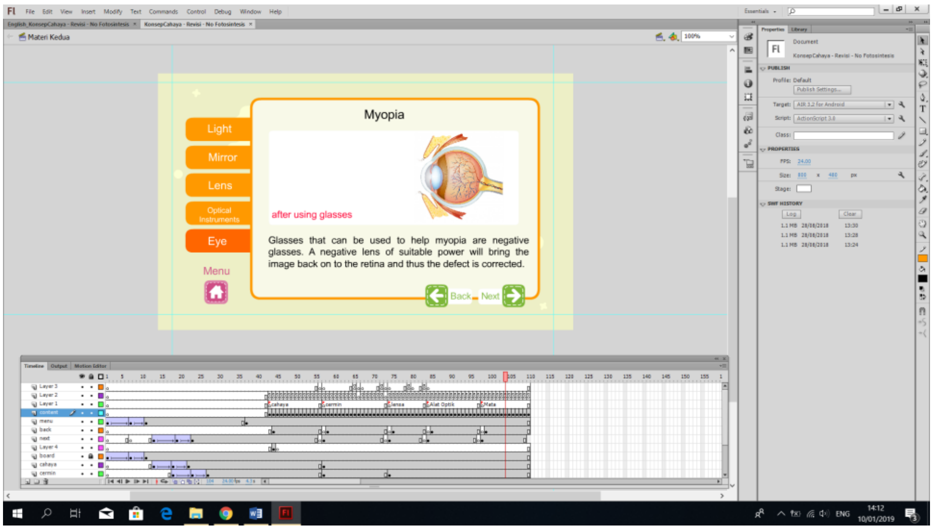
3. Menu



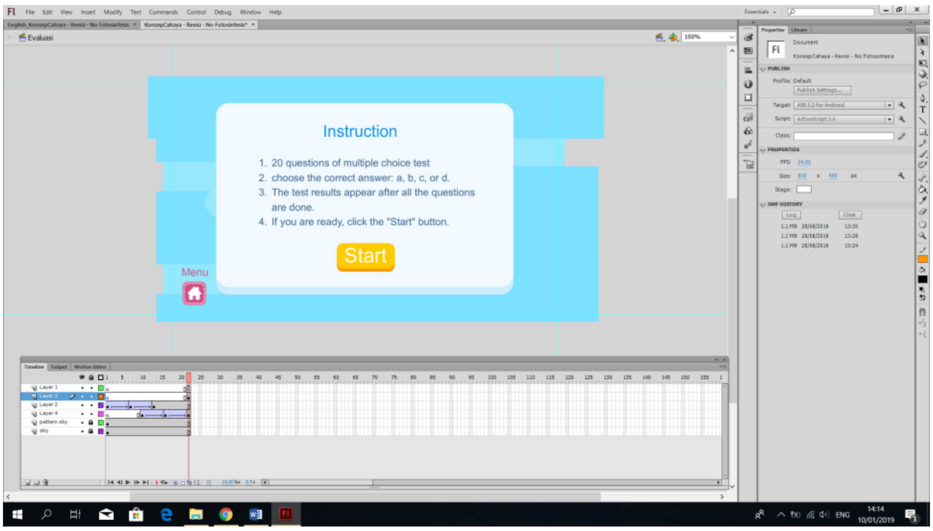
4. Competency



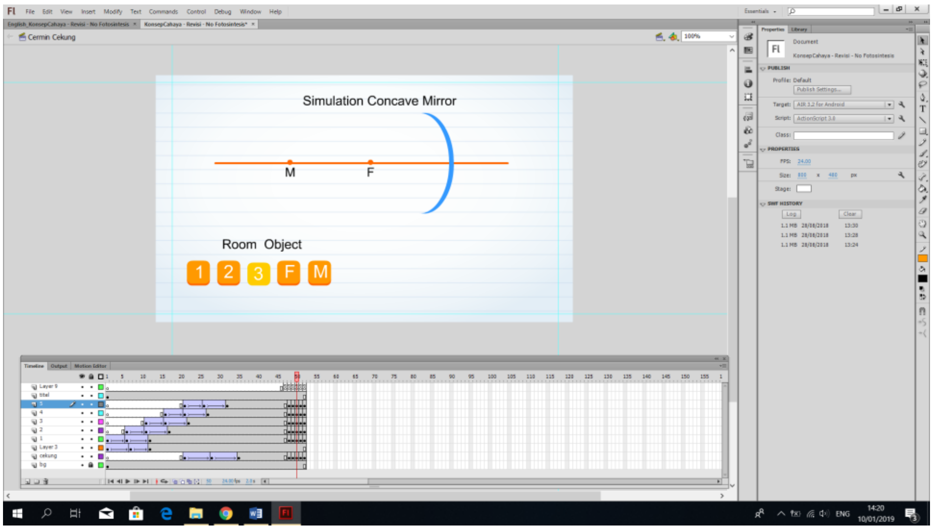
5. Main Teaching Material



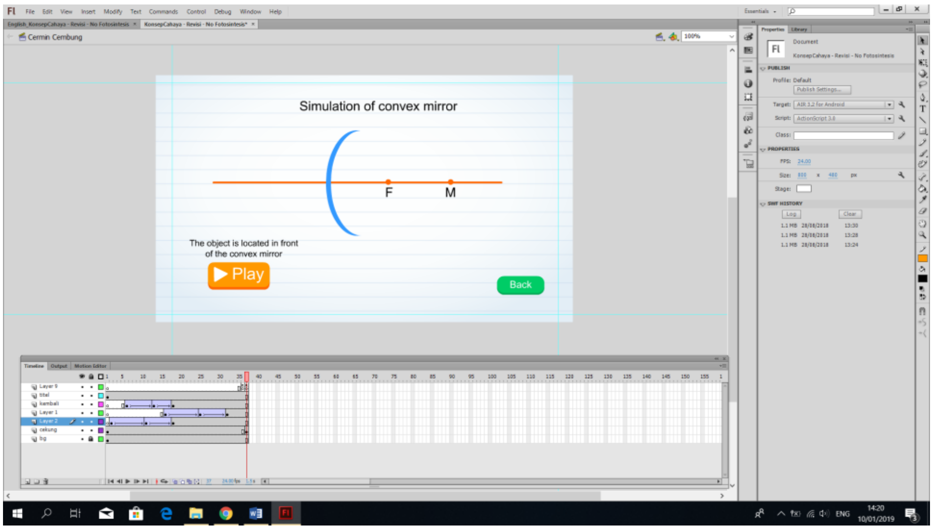
6. Evaluation



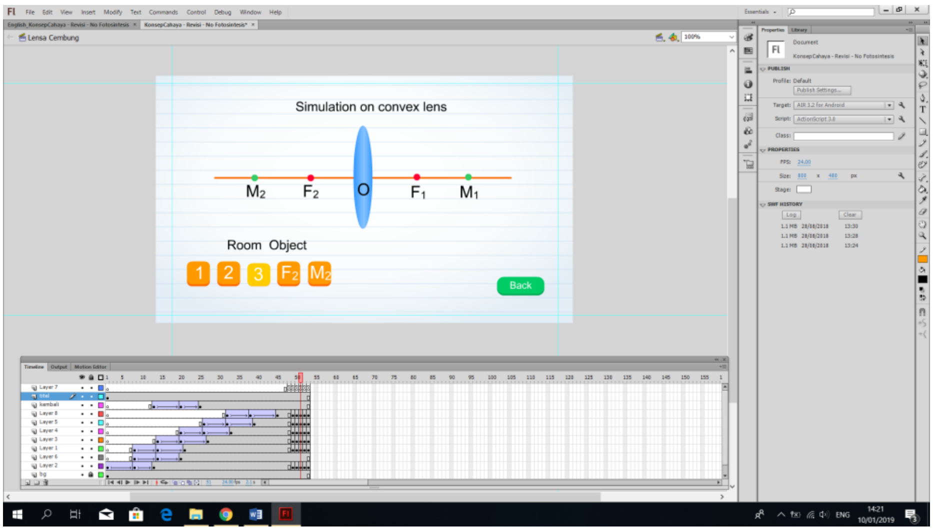
7. Simulation of concave mirror



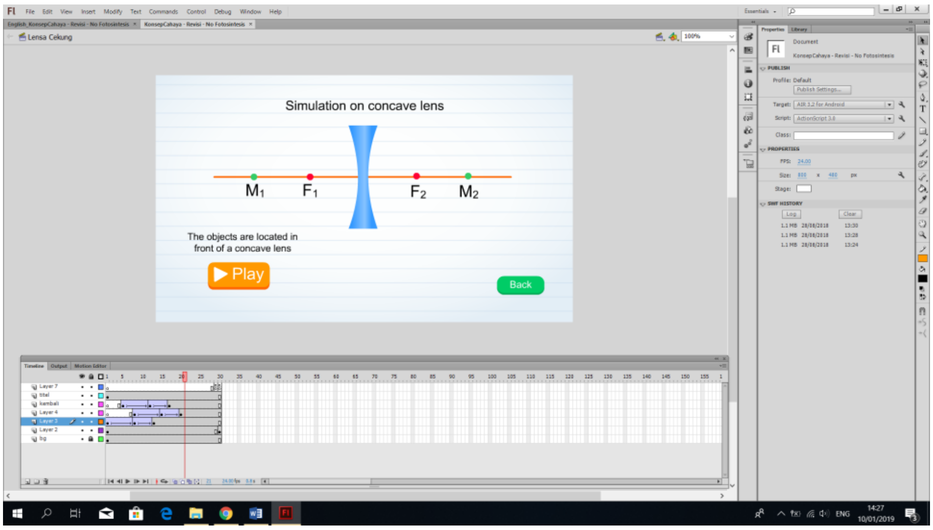
8. Simulation of convex mirror



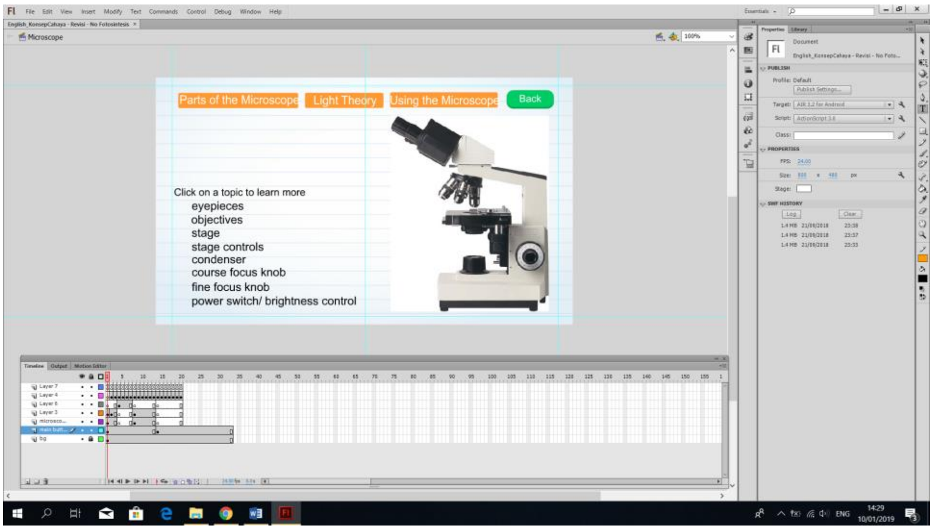
9. Simulation of convex lens



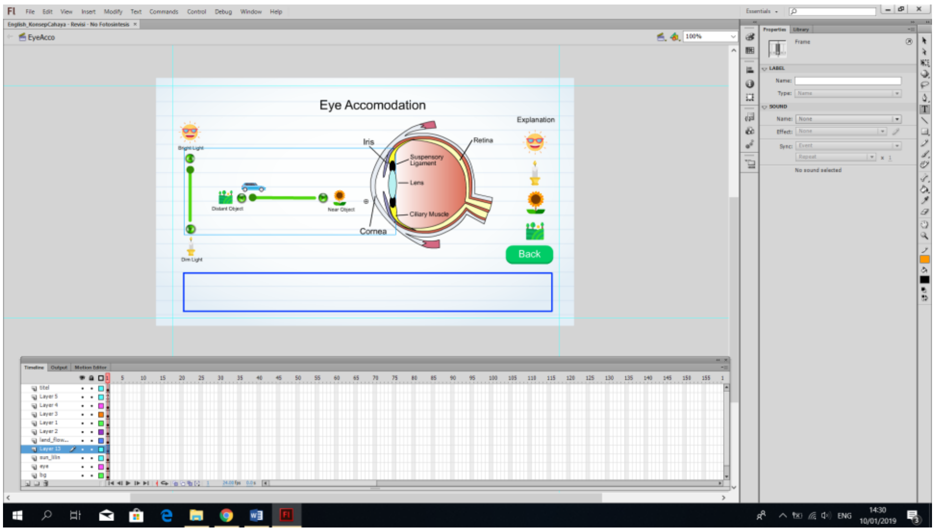
10. Simulation of concave lens



11. Simulation of microscope



12. Simulation of eye accommodation



Appendix 3. Permission Letter

HIROSHIMA UNIVERSITY
Graduate School for International Development and Cooperation
1-5-1 Kagamiyama Higashi-Hiroshima, Hiroshima 739-8529 JAPAN
PHONE +81-82-424-5902 FAX +81-82-424-6904

IDEC

March 14 , 2018

REQUEST FOR PERMISSION TO CONDUCT RESEARCH

To Whom It my Concern

Dear Mr/Mrs,

I am writing this letter to seek your consent for the student below to conduct the research in your school.

Name	: ARIF WIDIYATMOKO
Student Number	: D161086
Division	: Educational Development and Cultural and Regional Studies
Faculty	: Graduate School for International Development and Cooperation, Hiroshima University, Japan

The proposed topic of the research is "The Effectiveness of Simulation for Enhancing Conceptual Understanding on Light and Optical Instruments". The duration of the research is from March to April 2018.

Thank you very much for your attention. Your approval to conduct this research will be greatly appreciated. If you require any additional information, please do not hesitate to contact IDEC students support office.

Sincerely yours,

OFFICIAL SEAL OF
THE UNIVERSITY

Takuya Baba, Ph.D.
Dean and Professor
Graduate School for International
Development and Cooperation (IDEC),
HIROSHIMA UNIVERSITY

PEMERINTAH KOTA SEMARANG
DINAS PENDIDIKAN
Jalan Dr. Wahidin No. 118, Telp. (024) 8412180, Fax. (024) 8317752
Semarang – 50254
website: www.disdik.semarangkota.go.id, e-mail: disdik@semarangkota.go.id

SURAT IZIN KEPALA DINAS PENDIDIKAN KOTA SEMARANG

Nomor : 070 / 3033

TENTANG
IZIN PENELITIAN

Dasar : Surat dari Dean and Professor Graduate School For International Development and Cooperation (IDEC) Hiroshima University tanggal 14 Maret 2018 perihal Request For Permission To Conduct Research, dengan ini Kepala Dinas Pendidikan Kota Semarang,

MEMBERIKAN IZIN

Kepada mahasiswa ;

Nama	: ARIF WIDIYATMOKO
NIM	: D161086
Perguruan Tinggi	: Hiroshima University, Japan
Judul Penelitian	: The Effectiveness of Simulation for Enhancing Conceptual Understanding on Light and Optical Intruments
Tempat Penelitian	: SMP N 6, SMP N 7, SMP N 31 dan SMP N 41 Semarang

dengan memperhatikan hal-hal sebagai berikut ;

1. Saat penelitian tidak mengganggu proses kegiatan belajar dan mengajar pada Sekolah tersebut,
2. Menaati peraturan dan ketentuan yang berlaku pada Sekolah tersebut ,
3. Hasil penelitian tidak dipublikasikan untuk mencari keuntungan / kepentingan lain,
4. Kegiatan penelitian dilaksanakan pada Bulan Maret 2018 s.d April 2018,
5. Menyampaikan laporan kepada Kepala Dinas Pendidikan Kota Semarang segera setelah selesai melaksanakan penelitian.

Surat izin penelitian ini, untuk dapat dipergunakan sebagaimana mestinya.

Ditetapkan di : Semarang
Pada tanggal : 27 Maret 2018

An. KEPALA DINAS PENDIDIKAN
KOTA SEMARANG
Sekretaris

PEMERINTAH KOTA SEMARANG DINAS PENDIDIKAN

Ir. GUNAWAN WICAKSONO
Pembina Tk. I
NIP. 196007031990031009

Tembusan Yth ;

1. Kepala Dinas Pendidikan Kota Semarang (sebagai laporan)
2. Kepala SMP N 6 Semarang
3. Kepala SMP N 7 Semarang
4. Kepala SMP N 31 Semarang
5. Kepala SMP N 41 Semarang
6. Pertinggal

PEMERINTAH KOTA SEMARANG
DINAS PENDIDIKAN
SEKOLAH MENENGAH PERTAMA (SMP) NEGERI 6 SEMARANG

Jl. Pattimura No. 9 Telp. (024) 3544024 Fax. (024) 3544024 Semarang 50123
E-mail : s
mp6semarang@Yahoo.com Web Site : http://smpn6smg.sch.id

SURAT KETERANG

Nomor : 422/ 306

Yang bertanda tangan di bawah ini :

- Nama : H. Suprano, S.Pd, M. Pd.
- N I P : 19640101 198501 1 003.
- Jabatan : Kepala Sekolah.

Menerangkan dengan sebenarnya bahwa:

- Nama : Arif Widiyatmoko.
- **N I M : D161086**
- Perguruan tinggi : Hiroshima University, Japan

Saudara tersebut telah melaksanakan Penelitian Judul:

"THE EFFECTIVENESS OF SIMULATION FOR ENHANCING CONCEPTUAL UNDERSTANDING ON LIGHT AND OPTICAL INTRUMENTS "

Kegiatan penelitian dilaksanakan pada Maret s.d April 2018 yang dilaksanakan sesuai dengan prosedu.

Demikian surat keterangan ini buat, kepada yang bersangkutan untuk dapat dipergunakan sebagaimana mestinya.

Semarang, 10 April 2018
Kepala Sekolah,

PEMERINTAH KOTA SEMARANG SEKOLAH MENENGAH PERTAMA (SMP) 6 DINAS PENDIDIKAN

H. Suparno, S.Pd.,M.Pd.
NIP 19640101 198501 1 003

PEMERINTAH KOTA SEMARANG
DINAS PENDIDIKAN
SMP NEGERI 7 SEMARANG
Jl. Imam Bonjol No. 191 A Telp. 3540213 Kode Pos 50131 Semarang

SURAT KETERANGAN
NOMOR : 422 / 134

Berdasarkan surat dari Dean and Professor Graduate School For Internasional Development and Cooperation (IDEC) Hiroshima University tanggal 14 Maret 2018 Tentang Request For Permission To Conduct Research dengan ini Kepala SMP Negeri 7 Semarang menerangkan bahwa :

Nama	:	ARIF WIDIYATMOKO
NIM	:	D161086
Perguruan Tinggi	:	Hiroshima University, Japan
Judul Penelitian	:	**The Effectiveness Of Simulation For Enhancing Conceptual Understanding On Light and Optical Intrument.**

Yang bersangkutan telah melaksanakan Penelitian di SMP Negeri 7 Semarang pada bulan Maret s.d April 2018

Demikian surat keterangan ini dapat dipergunakan seperlunya.

Semarang, 7 April 2018

Kepala SMP Negeri 7 Semarang.

PEMERINTAH KOTA SEMARANG SEKOLAH MENENGAH PERTAMA (SMP) 7 DINAS PENDIDIKAN

Drs. R. Sutrisno
NIP. 19631103 198803 1 010

PEMERINTAH KOTA SEMARANG
DINAS PENDIDIKAN
SMP N 41 SEMARANG
SEKOLAH STANDAR NASIONAL (SSN)
Jl. Cepoko Utara, Gunungpati Semarang Telp. (024) 76921757
Email :smp-41semarang@yahoo.com

SURAT KETERANGAN
Nomer : 420/218/2018

Yang bertanda tangan di bawah ini :

Nama	:	Drs. Puryadi,M.Pd.
NIP	:	196408231989021001
Pangkat /Golongan	:	Pembina /IV a
Jabatan	:	Kepala Sekolah
Unit Kerja	:	SMP 41 Semarang

Menerangkan bahwa :

Nama	:	Arif Widiyatmoko
NIM	:	D161086
Perguruan Tinggi	:	Hiroshima University,Japan.

Telah melakukan penelitian di SMP N 41 Semarang dengan judul " The EffectivenessOf Simulation For Enhancing Conceptual Understanding on Light and Optical Intruments ". Pada bulan Maret s / d April 2018.

Demikian surat keterangan ini di buat untuk dapat di pergunakan sebagaimana mestinya.

Semarang, 9 April 2018
Kepala Sekolah,

PEMERINTAH KOTA SEMARANG
SEKOLAH MENENGAH PERTAMA (SMP) 41
DINAS PENDIDIKAN

Drs. Puryadi,M.Pd.
NIP. 196408231989021001