1. A Review of Misconception in Physics The Diagnosis, Causes.pdf

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A Review of Misconception in Physics: The Diagnosis, Causes, and Remediation

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ABSTRACT
The difference between students' ideas and scientific conceptions, is called misconceptions. Physics learning needs to be designed by teachers to eradicate misconceptions. This paper provides a review of 72 international journal articles on diagnosis methods, causes, and ways of remediating misconceptions that have been published between 2005-2020. The results obtained various diagnostic tools for physics misconceptions: interviews, open-ended tests, multiple-choice tests, and multiple-tier tests. Knowledge of some causes and the ability to diagnose becomes the basis for determining remediation strategies or preventing misconceptions. Interviews are suitable for revealing new misconceptions with a few participants, while the four-tier test is more effective for many participants. The most effective remediation strategies through the conceptual change approach are Simulation-Based Experiment, Conceptual Change Texts, and Inquiry-Based Learning. The development of diagnostic tools and remediation methods remains a more challenging topic for future research.

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Introduction

The constructivist approach in learning emphasizes student activities to construct a conceptual understanding. Students construct their knowledge by matching new facts or new concepts obtained in class with mental models based on their life experiences (Allen, 2014; Gomez, 2016; Konicek-Moran & Keeley, 2015). Synchronizing new facts or concepts with students' mental models becomes a constructive learning challenge. The learning process must consider the internal cognitive structure and external reality to be consistent according to Piaget's Theory with the support of social factors (Jenkins, 2000; Toh et al., 2003; Weil-Barais, 2001; Windschitl, 2002), to form a correct conceptual understanding (Arends, 2012; Seatter, 2003). The difference of existing concepts from scientific concepts (incorrect belief) becomes barriers in learning, called misconceptions (Allen, 2014; Clement et al., 1989; Driver & Easley, 1978; Helm, 1980; Neidorf et al., 2020). Misconceptions are also defined with different terms such as "alternative conceptions" (Klammer, 1998), "naive beliefs" (McCloskey et al., 1980), and "mental models" (Greca & Moreira, 2002).

Students' experiences about physical phenomena in life can raise wrong preconceived ideas of physical concepts or misconceptions (Neidorf et al., 2020). The knowledge construction determined from students' personal experiences tends not inlining with scientific knowledge, that also called alternative frameworks, intuitive beliefs, preconceptions, spontaneous critical thinking, children's science, and naïve beliefs (Karpudewan et al., 2017). The National Research Council (1997), the United States National Academies of Sciences, Engineering, and Medicine, classify misconceptions as preconceived notions, nonscientific beliefs, conceptual misunderstandings, vernacular misconceptions, and factual misconceptions. Misconceptions occur when students deliberate physical phenomena using their minds and confidence of being able to explain them with the right knowledge (Allen, 2014; Krebs, 1999). If their knowledge is interconnected with new facts that make sense according to students, then misconceptions will strengthen and complicated (Allen, 2014). That is, the identification of students' initial knowledge needs to be done before introducing new facts or concepts in learning. It is intended that learning does not complicate misconceptions but can eradicate misconceptions.

Misconceptions brought by students in the learning process will cause cognitive conflict when allowing new empirical concepts or facts (Kang et al., 2010; Labobar et al., 2017; Ramsburg & Ohlsson, 2016). The importance is students can be frustrated and disturbed expectations (Chen et al., 2019). Students become lazy to learn because they are frustrated or become lazy to explore deeper knowledge because of overconfidence (disturbed expectation). This becomes a barrier for students to build and deepen their understanding of concepts in learning (Allen, 2014; Chen et al., 2019; Verkade et al., 2017). Indeed worse, misconceptions also have a cumulative impact on students, extending from basic education even to the point where they have a certain level of expertise (Chen et al., 2019; Potvin & Cyr, 2017), for example, these students have become teachers. More critical, the misconception will be transmitted to students again, since one of the sources of misconception is the teacher (Arends, 2012; Resbiantoro & Nugraha, 2017; Skamp, 2012; Soeharto et al., 2019). If students' conceptual understandings are not correct, it will inhibit the ability to invent and not be able to solve problems (Singh, 2007; Vosniadou, 2019). The conceptual understanding, thinking abilities, and problem-solving abilities are the expected outcomes in 21st-century science learning, including physics.

Educators, education experts, and business leaders have developed the P21 Framework for 21st Century Learning, which is used by thousands of educators and hundreds of schools in the U.S. UNESCO's education Task Force with experts associated with the OECD's Program for International Student Assessment (PISA) and the International Association for the Advancement of Educational Achievement have also formulated the Assessment and Teaching of Twenty-First Century Skills (ATC21S). Implementation of the P21 and ATC21S frameworks began in the United States but has spread to Canada, the United Kingdom, New Zealand, and through national and international organizations such as APEC and OECD. Based on P21 (is based in the USA) and ATC21S (was co-founded by the governments of Australia, the USA, Finland, and Singapore), the frameworks of 21st-century skills include critical thinking and problem-solving as targets for achievement in the cognitive area (Battelle for Kids, 2019; Binkley et al., 2012). If students have any misconceptions, then the conceptual change is required to remediate misconceptions (Chi & Roscoe, 2002; Stump, 2015). Conceptual change is able to bring the ability of analogical thinking (Thagard, 2012), reasoning (Stump, 2015), and critical thinking, so students have a deep understanding (Chi & Roscoe, 2002; Treagust et al., 2017). The remediation of misconceptions can support 21st-century learning goals. Learning must focus on eliminating students' misconceptions, which means that the teacher must obtain a misconception diagnosis before carrying out learning (Ilyas & Saeed, 2018). For conducting a conceptual change approach, teachers must understand misconceptions in physics, from the process of diagnosis, causes, to the remediation process (Gomez-Zwiep, 2008; Qian et al., 2019; Resbiantoro, 2016).

Kumandaş et al. (2019) has published their analysis of biological misconception research in Turkey. They have compiled in a meta-synthesis are containing and comparing purposes, research methods, data collection instruments, and research findings. The analysis had been carried out on 67 articles published in Turkey. Gurel et al. (2015) have provided any comparison of diagnostic instruments in science to assess students' misconceptions. They have found 273 articles between 1980-

2014 to reveal the strengths and weaknesses of each diagnostic tool. These two articles inspired us to reveal the results of misconception research in physics. The results of these studies include diagnostic instruments, remediation methods, causes of misconceptions, and any physics topics that have not been explored.

The awareness of misconceptions is needed by teachers and other practitioners because of the complexity consequence, even impeding the attainment of 21st-century skills. The diagnosis of misconception in physics must be known by the teachers for outlining the remediation strategies. The questions to be answered are: (1) what diagnostic instruments are effective for diagnosing physics misconceptions?, (2) how to do effective misconception remediation?, and (3) what topics are common in the study of misconceptions and what topics are still not much explored? The authors have reviewed several international papers related to misconceptions in physics for the last sixteen years (2005-2020) to answer these questions. The answers to these questions provide recommendations and can become a reference for studying misconceptions of physics in the future.

Methods

Identifying Journal Articles

Identification was performed by exploring various databases for international journals, including ScienceDirect, SpringerLink, Taylor & Francis Online, and Wiley Online Library. Literature was identified at the end of 2020. The category of publication time queried was 2005-2020. The search keywords were "misconception in physics" and "alternative conceptions in physics". All search results were collected into one database to filter any duplicated articles. As a result, a total of 93 journal articles were obtained with details: 39 in ScienceDirect, 26 in SpringerLink, 13 in Taylor & Francis Online, and 15 in the Wiley Online Library. The next step was the abstract selection process, 21 non-research articles (general review and book review) were deleted so that the remaining 72 articles were read, analyzed, and coded using a spreadsheet program.

Coding Scheme Employed

The article coding was based on a scheme adapted from a systematic approach for literature review such as Lee et al. (2009). Experts in the fields of article review, meta-analysis, and physics learning were involved to advise the credibility and trustworthiness of the coding process based on this approach. Triangulation of sources to test the credibility of the data is done by checking the data obtained through several sources (reviewers) and commonly agreed. Experts audit all stages of the coding process. There are four main categories that the author used to understand each article in the review process, specifically:

- Basic data: author, publication year, journal, research location
- Research methodology: research approaches, methods, research objects, data collection instruments, analytical methods, and research results
- Content analysis: how to diagnose misconceptions, causes of misconceptions, and the process of remediation or elimination of misconceptions
- Discussion: the issues discussed the projected development of the problem, and the author's comments.

Based on these four categories, the author was able to view and outline the trends (trends), problems that arise, and future research directions clearly. The coding scheme was compiled in a form that supports the literature review process (Prasad, 2008).

Findings

Of the 72 articles that were reviewed in this study, the largest number was published in 2014 (14%). Over the last seven years, from 2014 to 2020, an addition had occurred in the number of articles about physics misconceptions. There was a decline in 2016 and 2018 during that period, but it increased sharply again in 2019 and fell again in 2020. In detail, the number of publications data are shown in Figure 1. Based on that data, misconceptions are still very exciting for educational researchers.

Figure 1

Percentages of Studies about Misconception across Years (2005-2020)

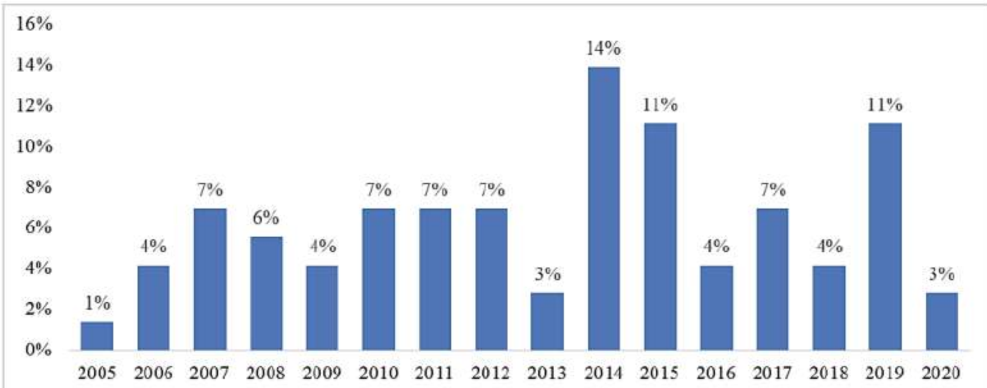
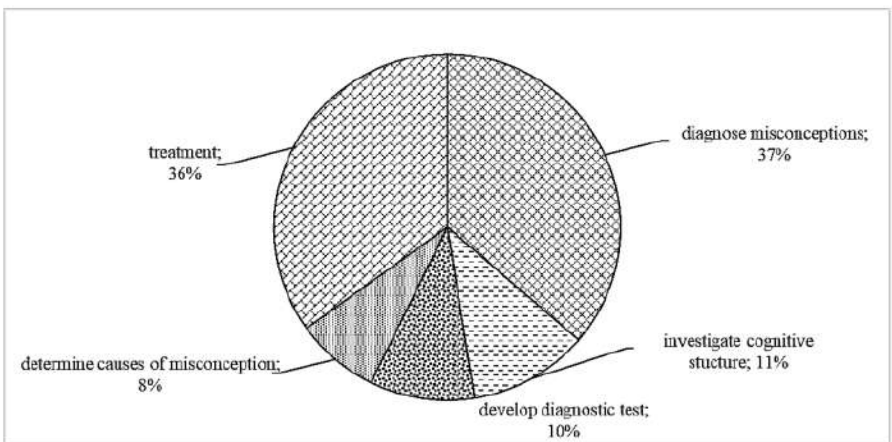


Figure 2

Purposes of the Overall Studies



There are five research purposes of the articles as a result of this study, including diagnosing misconceptions, investigating cognitive structures, developing diagnostic tests, determining causes of misconception, and treating misconceptions (remediation). Most of the articles have the aim to diagnose misconceptions (37% or 26 articles) and carry out the treatment or remediation of misconceptions (36% or 25 articles), as shown in Figure 2. The remediation process of misconception is carried out through eight methods in learning, particularly simulation-based experiments, conceptual change texts, inquiry-based learning, multimedia instruction, collaborative learning, laboratory experiments, and concept mapping. The simulation-based experiment is the most widely used method in the remediation process. The number of each method used for remediation of misconceptions is shown in Figure 3.

Figure 3

Treatment Methods Used for Remediating Misconceptions

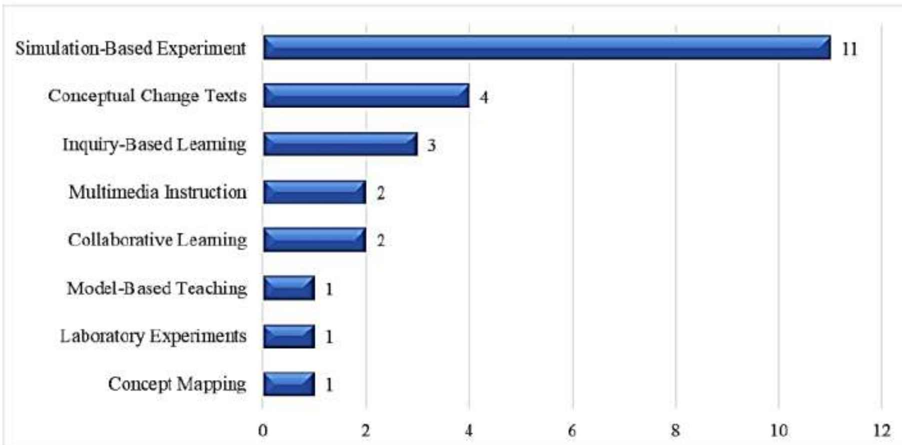
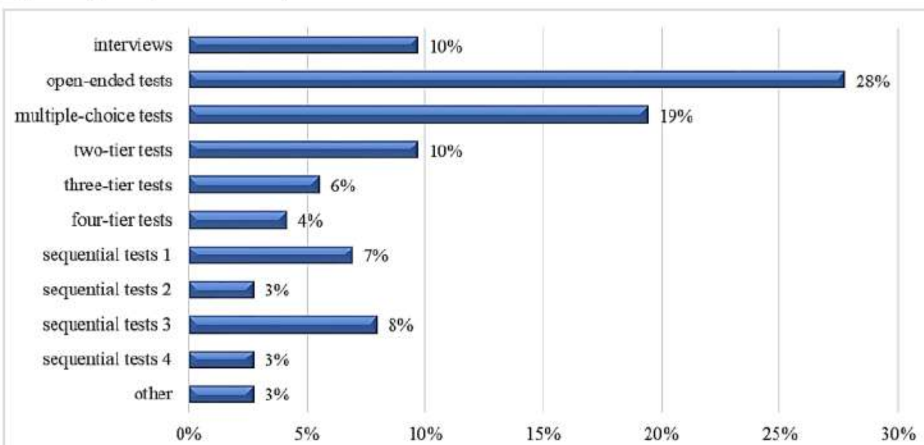


Figure 4

Tools for Diagnosing the Misconception



Diagnostic tools become a principal component for investigating students' misconceptions in several physics concepts. Based on this review, there are six types of diagnostic tools used, namely interviews, open-ended tests, multiple-choice tests, two-tier tests, three-tier tests, and four-tier tests. The researchers also used sequential tests, i.e. multiple-choice tests followed by open-ended tests (sequence 1), multiple-choice tests followed by interviews (sequence 2), open-ended tests followed by interviews (sequence 3), and interviews continued observations (sequence 4). Open-ended tests are the most widely used tools in 28% of articles, followed by multiple-choice tests in 19% of articles as shown in Figure 4.

The research approaches used in the articles are categorized into three types: qualitative, quantitative, and mixed methods. This review, visualized in Figure 5, shows that 43% use qualitative, 39% quantitative, and only 18% use mixed methods. Most articles use descriptive techniques to diagnose misconceptions and inferential statistics to test the effectiveness of the treatments performed.

Figure 5

The Research Methodology of Misconception Studies

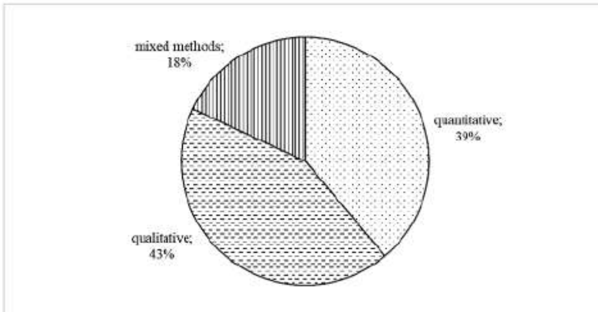
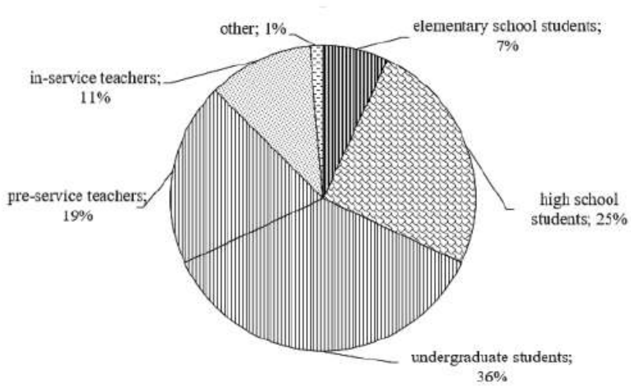


Figure 6

The Participants of Studies

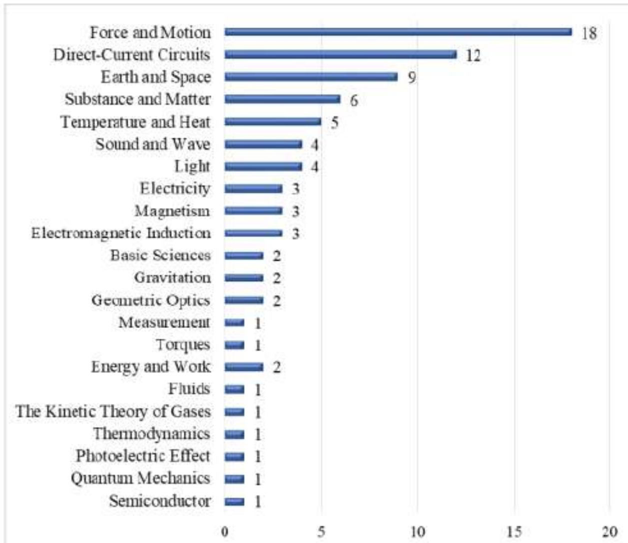


Various participants are part of the research in the articles that have been reviewed. Participants are categorized into five types: undergraduate students, high school students, elementary school students, pre-service teachers, and in-service teachers. All of the participants (Figure 6) form a chain of misconceptions. That is, misconceptions may occur at one level of education that can continue to be carried at a higher level of education, even when becoming a teacher. Further analysis will be reviewed in the discussion section on the causes of misconceptions.

Figure 7 shows the distribution of physics topics analyzed in articles across the year. Physics topics broadly consist of the following areas: mechanics, oscillations and mechanical waves, thermodynamics, electricity and magnetism, light and optics, modern physics, earth and space. These topics can be separated into several subtopics. Each article exposes misconceptions on topics or subtopics in physics. The most popular subtopic as an object of research is force and motion misconception (18 articles) and followed by direct-current circuits (12 articles). Many subtopics have not been explored in physics misconception research.

Figure 7

Topics Analyzed in Studies



Discussion

The analysis results of the articles give insights related to international studies of misconceptions in physics over the last sixteen years (2005-2020). Our purposes are to expose the diagnostic tools and remediation strategies for misconceptions, as well as to find out the causes of these misconceptions. During the investigation, we obtained facts about research trends, research purposes, research methodology, and the participants in each article. Two other studies conducted a review and served as references in the following discussion. Kumandaş et al. (2019) have addressed misconceptions in biology and Gurel et al. (2015) have addressed the comparison of instruments for the diagnosis of misconceptions in science. Both studies provided additional insights for discussing physics misconceptions in this study.

Research Purposes across Years

Most of the articles in this study (37%) have the purpose to identify or diagnose misconceptions in physics. Most diagnoses were made into undergraduate students (36%), high school students (25%), and pre-service teachers (19%). Diagnosis is needed to raise awareness about the existence of misconceptions regarding the students of higher education and the pre-service teachers. The need for diagnostic tools has been supported by studies that have developed diagnostic tests for misconceptions (10%). The result of instruments can be adapted to diagnose misconceptions according to the topics. Among the diagnostic tests that have been developed are multiple-choice tests and multiple-tier tests (two-tier, three-tier, and four-tier). Each of those instruments has different characteristics and is discussed in a separate sub-discussion. The diagnosis of misconceptions becomes the initial round of an educator in learning to build scientific conceptions (Nitko & Brookhart, 2014; Seel et al., 2017; Topalsan & Bayram, 2019; Wind & Gale, 2015). The accumulation of the not understood concepts from elementary education to higher education plus daily experiences can trigger misconceptions. Misconceptions can be brought by students from elementary school to university level (Gönen, 2008; Potvin & Cyr, 2017). The remediation of misconceptions needs to be performed before the undergraduate students and the pre-service teachers enroll in a professional career with the provision of 21st-century learning competencies.

Most articles (36%) in this study aim to determine the effective remediation strategies for developing scientific conceptions. The effectiveness was determined by comparing misconceptions before and after the learning process. Misconceptions identification is an important part of remediation because it helps teachers to plan learning strategies accordingly (Knowles et al., 2005). To support that, many studies (10%) have investigated the students' cognitive structures. Cognitive structure investigation gives the teacher ideas about how students think about a concept, specifically the way students link concepts in their minds (Kumandaş et al., 2019). The largest participant (36%) in the articles were undergraduate students, followed by high school students (26%), and pre-service teachers (20%). At the level of higher education, undergraduate students tend to have complex thought abstractions. If such thought develops in the realm of science plus daily experiences and common sense concepts without the construction of scientific knowledge, it can lead to misconceptions (Krebs, 1999; Resbiantoro & Nugraha, 2017). In pre-service teachers, a misconception is a concern for researchers because it has the potential to be transferred to students when they become teachers later (Kumandaş et al., 2019).

Misconceptions can be likened to "diseases" in the cognitive structure of students. Educators are like a doctor who will treat the disease. Before starting the treatment, the doctor must diagnose the patient's condition. Diagnosis of misconceptions in students' cognitive structures is very important for the learning process to be effective and meaningful. Learning requires strategies to eliminate and prevent misconceptions. Two important purposes in the study of misconceptions have been carried out over the last 16 years, which are the diagnosis and treatment of misconceptions. The results of the diagnosis of misconceptions from these studies can be used as a reference for potential misconceptions in several physics topics. Meanwhile, several effective strategies for conducting treatment can be adapted and optimized to eliminate or prevent physics misconceptions.

Diagnostic Tools

Various instruments for diagnosing misconceptions have been developed and used. Diagnostic tools for misconceptions are categorized in interviews, open-ended tests, multiple-choice tests, multiple-tier tests, and sequential tests. Each form of the test has advantages and disadvantages. The test arrangement regards the purposes, participants, and fitness of the material characteristics with the test structure. A diagnosis is a form of assessment that is very precise for identifying misconceptions because it has the purpose of identifying learning outcomes that are not yet understood by students as well as the causes for remediation later (Nitko & Brookhart, 2014). The research development on misconceptions is greatly influenced by the development of diagnostic tests (Mintzes et al., 2005). The distribution of diagnostic tests for physics concepts is still limited in Figure 7, which means it still needs to be developed. The results of the misconception diagnosis will determine the steps of a teacher about their learning going forward (Harlen, 2001; Nitko & Brookhart, 2014).

Open-ended tests were chosen by most researchers (28%). The characteristic of this test is that it can explore students' ideas through the answers or responses provided (Mintzes et al., 2005). Through content analysis of the responses, researchers can identify errors and misconceptions in students (Nitko & Brookhart, 2014). The advantage of open-ended tests is that students can convey their understanding of concepts in their language, and maybe even responses that are unexpected by researchers (Kaltakci-Gurel et al., 2015). Sadler has stated that open-ended tests have the advantage of being able to reveal unexpected errors or misconceptions (Mintzes et al., 2005). While its weakness takes a long time to analyze student responses, including difficulties in scoring and categorizing responses (Kaltakci-Gurel et al., 2015). This reason causes open-ended tests less appropriate to be employed in research with large numbers of participants. The first use of open-ended tests as diagnostic tools had been published by Andersson & Kärrqvist (1983); Palacios et al. (1989); Langley et al. (1997); and Colin et al. (2002). The use of open-ended tests in reviewed articles can be seen in Appendix 1.

Multiple-choice tests (MCT) become the most choices after open-ended tests for diagnosing misconceptions. The form of this test generally consists of two parts, stem (problem to be tested) and a list of possible answers or multiple-choice items (Fisher & Frey, 2007). Multiple-choice items carry correct or best answer choices and distractors for questions or problems that have been submitted in the stem (Nitko & Brookhart, 2014). Distractors are answer choices that seem right for students who lack understanding, even though actually wrong. If students choose the distractors, then indicate students have misconceptions. Many kinds of MCT to identify the conceptual understanding of physics, most of them have been shared on the PhysPort page by the American Association of Physics Teachers (AAPT). An example is for testing the basic concepts of mechanics, Force Concept Inventory (FCI) has been developed in the form of MCT. Hestenes et al. (1992) as the developer has stated that one of the uses of the FCI is to diagnose misconceptions. FCI has been very popular among international researchers for testing the students' conceptual understanding and misconceptions. Many FCI users in their research based on this review are Bayraktar (2009), Martín-blas et al. (2010), Taasoobshirazi et al. (2011), Fazio & Battaglia (2018), and Franco et al. (2012). FCI is usually adapted and translated by researchers into their language, for instance, Bayraktar (2009) had translated FCI to Turkish. Recently researchers using MCT to identify misconceptions are shown in Appendix 1.

The selection of MCT as a diagnostic tool must consider the advantages as well as weaknesses. Time efficiency for more objective analysis of answers and scoring is an advantage of MCT (Kaltakci-Gurel et al., 2015; Mintzes et al., 2005; Nitko & Brookhart, 2014). So even though the number of participants in the study is very large, the time needed for the analysis of answers will be shorter when compared to open-ended tests. Some weaknesses that need to be noticed from MCT are not being able to investigate students' ideas in depth, there are correct answers even if it's just a guess, and the difficulty of arranging conforming items (Kaltakci-Gurel et al., 2015; Mintzes et al., 2005; Nitko & Brookhart, 2014). Student ideas cannot be investigated in-depth because of the limited answer choices. That closes the possibility of finding new patterns of misconception. The right answers are not certainly authentic because of any possibility that students only guessed and inadequate to explain the reasons. Likewise, students who answer incorrectly cannot be concluded having misconceptions because of any possibility that students just answered without knowledge. In their publications on FCI, Hestenes et al. (1992) also suggested following up on students' wrong answers through interviews related to reasons for their choice to ensure misconceptions. The arrangement of stem and distractors are a challenge to develop well-constructed items. Stem and distractors are usually in the form of common misconceptions obtained from literature studies, interviews, or open-ended questions that are conducted first, such as Prince et al. (2012), Wind & Gale (2015), Gönen (2008), and Alwan (2011).

Interviews are a form of diagnostic assessment to identify student understanding, including misconceptions. This diagnostic method is used in 10% of the articles that have been reviewed. Through interviews, students' thinking errors can be detected in more detail (Nitko & Brookhart, 2014). Students' ideas and structure of conceptual understanding also can be revealed by interviews (Fisher & Frey, 2007; Mintzes et al., 2005). Because of those advantages, Hestenes et al. (1992) have said that interviews were able to confirm students' responses for revealing misconceptions. Some interview techniques that had been carried out by previous researchers are Clinical Interviews (Posner & Gertzog, 1982; Ross & Munby, 1991); Interview about Instances (IAI) (Osborne & Gilbert, 1980); Interview about Events (IAE) (Boujaoude, 1991); Individual Demonstration Interviews (Goldberg &

Mcdermott, 1986; 1987); Predict-Observe-Explain (POE) (Liew & Treagust, 1995); Teaching Experiment (Komorek & Duit, 2004), and others.

Based on the review, several articles used techniques that resembled interviews conducted by previous researchers, even though they did not mention them specifically. Paik et al. (2007), Kele et al. (2010), and Abrahams et al. (2015) used techniques that resembled Clinical Interviews by asking participants to explain briefly their conceptual understanding of physics. Thong & Gunstone (2008) asked a series of questions about electromagnetic phenomena, which resembled the IAI technique. Bell & Trundle (2008) asked participants to predict, observe the results of computer simulations, and explain the occurrence of these phenomena, in which the whole set of questions resembled the POE technique. Any challenges must be faced in the interviews, including a long time to obtain and analyze data, and require interviewing skills (Fisher & Frey, 2007; Mintzes et al., 2005; Nitko & Brookhart, 2014). If the results will be generalized, then interviews require a large number of participants (Kaltakci-Gurel et al., 2015). The power of interviews is being able to get in-depth information, even being able to find facts (misconceptions) that were unexpected before, such as the findings of Thong & Gunstone (2008).

Multiple-Tier Tests (MTT) include two-tier tests (2TT), three-tier tests (3TT), and four-tier tests (4TT). The basic structure of the three types of MTT is alike to MCT. There are conceptual questions along with the reasons for answers, including the questions to the answer confidence. All types of MTT have advantages such as MCT: time efficiency, fast and objective scoring, and ease for employing a large number of participants (Kaltakci-Gurel et al., 2015). The challenges while preparing MTT are also alike with MCT, as in determining the distractors. While the weaknesses of MTT are different for each type. The researchers who utilize MTT based on this study, are shown in Appendix 1.

The first type of MTT is 2TT. That consists of the first tier in the form of conceptual questions (content) and the second tier is the reason for the answer in the first tier (Griffard & Wandersee, 2001; Mintzes et al., 2005; Treagust, 1986). Two-tier tests were first published by Treagust (1986) which was then succeeded by many misconception researchers. As a preliminary test, 2TT can quickly identify misconceptions for planning proper learning. Griffard & Wandersee (2001) have evaluated the use of 2TT for diagnosing misconceptions and obtaining several weaknesses. Since each tier of 2TT is multiple-choice, there are indications that the participant uses the choice of reasoning (in the second tier) by guessing. So it cannot be determined whether the participants have conceptual understandings as a whole (lack of knowledge) or occurring misconceptions (Griffard & Wandersee, 2001; Kaltakci-Gurel et al., 2015). The misconception diagnosis using 2TT might not represent the authentic thinking of students because alternative answers have been prepared by answer items (Chang et al., 2007).

The second type of MTT is 3TT developed for covering the 2TT weaknesses. The lack of knowledge and misconception (overestimating judgment) is inadequate to differentiate by 2TT. Interviews must be conveyed to verify answers for specifying the lack of knowledge and misconception. Interviews are inefficient because it needs a longer time for diagnosing. Instead of interviewing, one more tier was added using the Certainty Response Index (CRI). CRI was used for verifying the participant's confidence in answers (Pesman & Eryilmaz, 2010). If the participant answers confidently with the wrong answer on the first or second tier, then it can be said to be a misconception, but if not sure, it is called a lack of knowledge (Turgut et al., 2011). The difference between misconception and lack of knowledge in the participant already be recognized by 3TT. There are still assuming any errors because maybe the participant beliefs of answers are not the same in both tiers (Kaltakci-Gurel et al., 2015). The first tier answer could be sure but the reason in the second tier is not sure, or vice versa.

Based on the lack of 3TT, the third type of MTT has been developed to add one tier more. 4TT eliminates the overestimated judgment category of a lack of knowledge (Kaltakci-gurel et al., 2017). The first tier is MCT with a distractor that leads to misconceptions. The second tier confirms the answer's confidence in the first tier. The third tier is the MCT reason for the answer in the first tier. The fourth tier confirms the confidence of the answer to the third tier. Misconceptions were shown if the students' answer of the first tier was "wrong", the second tier was "sure", the third tier was "wrong", and the fourth tier was "sure" (Kaltakci-gurel et al., 2015; 2017; Kaniawati et al., 2019). Thus 4TT was claimed to provide the most valid misconception judgment than 3TT and 2TT. In general, the development of 4TT has the same challenges as MCT when arranging distractors both in the first tier and third tier. That can be performed by studying literature about misconceptions that have been discovered or conducting initial diagnosis through interviews and open-ended tests.

Causes of Misconception

Misconceptions become a barrier to learning physics to achieve scientific conceptions. Besides focusing on the way of diagnosis, researchers must also investigate the causes or factors that contribute to students' misconceptions. Four main factors cause misconceptions, particularly the characteristics of teaching materials, teachers, students, and reference books (Erman, 2017). Halim et al. (2019), states that students, teachers, and teaching methods are the three main causes of misconception. Other beliefs about the factors that cause misconceptions are everyday experiences, language used, teachers, and textbooks (Widiyatmoko & Shimizu, 2018). Factors that cause misconceptions can be students, teachers, language used, teaching methods, characteristics of teaching materials, and reference books, by including everyday experiences into the student area.

Based on this review, researchers focus on teacher factors and teaching methods as causes of misconception. Both of these factors are areas that can be optimized to eradicate misconceptions. In the concept of formal learning, teachers are required to be able to implement teaching methods that present scientific explanations to students (Neidorf et al., 2020). There are several problems found related to those two factors based on this review. Some teachers lack insight into the misconceptions of their students, so they only focus on teaching without trying to apply the conceptual change approach (Gaigher, 2014; Moodley & Gaigher, 2019). Another obstruction that contributes to the occurrence of misconceptions is the lack of adequate learning time management (Aykutlu et al., 2015). This can be caused by a wide range of material as a result of curriculum demands or planning targets of the teachers themselves (Aykutlu et al., 2015). As a result, students only focus on memorizing without the possibility to generate scientific conceptions through the processes of thinking and learning activities.

Remediation of Misconceptions

An understanding of diagnostic techniques and causes of misconception is needed to determine remediation strategies. Remediation aims to turn their naive beliefs into scientific conceptions. The determination of remediation strategies is strongly influenced by the teacher's insight related to pedagogical knowledge. Several researchers in this review have given suggestions regarding remediation strategies using the conceptual change approach (see Appendix 2). Conceptual change is a mechanism that underlies meaningful learning processes, so students who initially do not understand become understand a concept (Mayer, 2002). More simply, Mayer (2002) states that conceptual change characteristics include cognitive processes and social processes in which students try to build coherent and useful knowledge. According to a constructivist perspective, knowledge is not transferred from teacher to student but is constructed by individuals through the process of assimilation and accommodation. The accommodation process is the principal mechanism for conceptual change and has been established in a framework called the Conceptual Change Model (CCM) by Posner et al. (1982). This model has been improved by Dole & Sinatra (1998) toward the Cognitive Reconstruction of Knowledge Model (CRKM) through blending the principle of the Elaboration Likelihood Model (ELM) which had previously been developed by Petty & Cacioppo (1986).

The conceptual change approach emphasizes that learning science should not merely convey information, but must guide students to understand their experiences in science (Mayer, 2002). The teacher must alter it into an appropriate science learning method. Based on this study, learning methods that are widely used to remediate misconceptions with a conceptual change approach are Simulation-Based Experiment (11 articles), Conceptual Change Text (4 articles), and Inquiry-Based Learning (3 articles). All of these learning methods focus on student activities, and the teacher guides as they reconstruct knowledge. By understanding the characteristics of that three learning methods, researchers and teachers can perform a conceptual change in physics. When referring to CCM, four conditions can be created in the learning method so that concept accommodation can occur, namely dissatisfaction, intelligible, plausible, and fruitfulness (Posner et al., 1982). The dissatisfaction condition occurs if the students are dealing with facts or problems that cannot be solved by understanding the prior concept and feeling that there is something wrong with their concept. Experiences during learning must be able to be used by students to develop scientific conceptions which are inherent (intelligible). Those conceptions must be plausible, at least for solving the problems that cannot be solved by prior conceptions. Plausibility is also shown by the consistency of a concept with other knowledge. The last condition is fruitfulness which means new conception relevance to the benefit of research issues that are continuously developing.

Simulation-Based Experiment (SBE) is the most widely used choice for remediation of misconceptions. The application of computer technology in learning continues to grow, along with the development of research in educational technology. Specifically, to support the remediation with the conceptual change approach, simulation is considered to be the most appropriate method. This refers to the characteristics of simulation that are able to advance various learning objectives of science, including science learning motivation, conceptual understanding, science process skills, and understanding the nature of science (National Research Council, 2011). Computer-based simulations offer a virtual learning environment that cannot be practised or emulated in real conditions (Januszewski & Molenda, 2008). Students can visualize, explore, and formulate scientific explanations for scientific phenomena that would otherwise be impossible to observe and manipulate (National Research Council, 2011). These are experiences offered by digital simulations and are suitable for building intelligible conditions in CCM.

Simulation potentially to be used in various approaches to teaching and learning, as didactical tools, as models and conveyance for complex concepts (Gibson & Baek, 2009), for discovery learning (Van Joolingen & De Jong, 1997), for experiential learning (Kolb, 2015), and predict-observe-explain (Kibirige et al., 2014). The keyword is an SBE able to provide concrete experiences, mediate interactions between learners and natural phenomena, and guide learners to draw conclusions based on the results of experiments. Zietsman & Hewson (1986) have been able to handle misconceptions by integrating microcomputer-based simulations and conceptual change strategies. DYNLAB, computer-based modelling has also been developed by Brna (1987) and is capable of confronting dynamics misconceptions. De Jong & Van Joolingen (1998) have also conducted studies on scientific discovery learning (SDL) with computer simulations. Another intervention has been carried out by Zacharia & Anderson (2003), who performed prior knowledge of computer-based simulations before the students conducted a laboratory experiment. In this case, that aims to establish plausibility conditions according to CCM.

SBE has any advantages if applied to the conceptual change approach. That is evidenced by its effectiveness for remediating misconceptions based on the results of existing studies. Implementing SBE is not as simple as imagined because it requires collaboration with software developers and animators. Besides, it needs much detailed planning to develop digital simulations. Any challenges in developing SBE according to Gibson & Baek (2009) include: (1) the complexity of the interface development and the attainment of the supporting devices; (2) limitations of SBE features that limit students exploration; (3) limited feedback due to the lack of adaptive systems like humans; (4) students must maintain focus because they interact with computers through multi-sensory systems; (5) when playing the simulation, students might not be able to drift into a part of the phenomenon; (6) students with weak computerized skills may be overwhelmed by playing simulations; (7) teachers must give enough direction to learners; and (8) SBE development is costly and difficult. If these challenges are not allowed well, students will miss meaningful experiences.

Conceptual Change Text (CCT) became the second most preferred method for remediating misconceptions. CCT is in the form of text with a CCM approach from Posner et al. (1982). CCT have first developed by Roth (1985) to help students to perform the four Posner conditions. If these four conditions are involved in CCT, then students will be advised to obtain the conceptual change when compared to traditional text that only focuses on composing new intelligible conceptions (Roth, 1985). Traditional texts can be formed into CCT by blending the conditions of conceptual change (Chambers & Andre, 1997; Wang & Andre, 1991).

Several sections in the CCT must exist to fulfill the four Posner conditions. The first section is the process of activation or identification of possible student misconceptions. At this segment, phenomenon descriptions or conceptual facts are presented, then students are asked to make predictions or explanations about it. The second section presents narrative texts about any misconceptions, which are commonly occurring in the concept. From both sections, students will undergo cognitive conflict or dissatisfaction conditions. Students will be curious to find scientific reasons that are intelligible and plausible. The descriptions are manifested in the third section by adapting from traditional texts. The final section presents a parallel study of misconceptions and scientific conceptions, then be continued by explanations related to future usage of the concept. To this section, a fruitfulness condition does achieve then students will be sure that the new concept will be useful.

CCT might be easier to develop than SBE because it is only based on text with the addition of images. Behind this convenience, many challenges must be allowed in using CCT for remediating misconceptions. Early in the CCT experimentation, Roth (1985) has advised that "poor readers" had a problem learning from texts because they had weak reading strategies. They have a problem with catching the essence of the text addressed. CCT is only effective given to students with much reading skills. That can be improved by class discussions (Guzzetti et al., 1997; Özkan, 2013). Low interest in reading is also a cause of ineffective usage of CCT (Wang & Andre, 1991). Students will feel more bored and tired if only dealing with text features (Chambers & Andre, 1997). A blend of visual elements is needed to overcome this, such as interesting diagrams and illustrations. Therefore, the use of CCT has developed towards digital, such as Computer Supported Conceptual Change (CSCCT) (Çepni, 2010).

Inquiry-Based Learning (IBL) can be the next option for remediating misconceptions. The essential characteristic of IBL is to actively engage students to construct knowledge through identifying problems, predicting solutions, and adapting new information (assimilation) to accommodation knowledge (Arends, 2012). The fundamental principle of IBL is the same as CCM, that is Piaget's constructivism. Vosniadou (2003) has views on the essential characteristics for learning that are following the CCM to restructure non-scientific conceptions: (1) generates conditions in which students can evaluate experiential evidence that confronts their ideas; (2) provides clear explanations related to scientific conception through modelling or analogy; (3) leads the demonstrations that prove scientific explanations; (4) promote the intentional learning that ensures students about the unities of conception. These features can be interpreted into IBL phases (Trundle et al., 2007). Inquiry allows students to explore their ideas and challenge their ability to explain a concept so that it undergoes the mechanism of conceptual change (Vosniadou, 2003). Through IBL, students will also get a deeper understanding of a concept and be able to apply it in various fields of life sciences (Saunders-Stewart et al., 2015).

Conclusion and Implications

A misconception is a common issue in learning physics that should not be ignored by teachers. The consequence of misconceptions is critical in reaching the learning objectives. This review shows a lot of scientific publications about misconceptions in physics for the last sixteen years. A high number of publications indicate that the studies in misconceptions are still challenging and exciting for all areas. Three areas in studying misconceptions are identifying misconceptions through diagnostic tests, perceiving the causes, and remediating misconceptions. The diagnosing misconceptions and the treatment for remediating misconceptions become the most popular research areas. Actually, the two research areas support each other, because there is a sequence of the process of diagnosis and remediation of misconceptions. Each has a development of diagnostic tools and remediation methods from across the years.

This review provides several essential points and recommendations for researchers or practitioners to better deal with misconceptions:

- The area of research on misconception is still wide, especially of diagnostic tests, misconception remediation strategies, and some unexplored physics topics.
- Interviews become a powerful technique to find out new misconceptions (which have not been identified previously)
- Four-tier tests are more effective for a large number of participants.
- The most effective of remediation strategies through the conceptual change approach are Simulation-Based Experiment, Conceptual Change Texts, and Inquiry-Based Learning.
- Prospective and pre-service teachers must be targeted for investigation so that they are aware of misconceptions and have an effort to eradicate them. Misconceptions mustn't enter professional careers when becoming teachers.
- Educational practitioners including teachers, educators, and curriculum developers can adapt the results of misconception research to be applied in physics learning.
- There are still many other psychological parameters that need to be investigated in future research. The effect of student communication, parenting, and social environment on misconceptions seem to be the topic of future investigations.

References

Abrahams, I., Homer, M., Sharpe, R., & Zhou, M. (2015). A comparative cross-cultural study of the prevalence and nature of misconceptions in physics amongst English and Chinese undergraduate students. *Research in Science & Technological Education*, *33*(1), 111–130. https://doi.org/10.1080/02635143.2014.987744

Allen, M. (2014). *Misconceptions in Primary Science 2nd Edition*. Open University Press.

Alwan, A. A. (2011). Misconception of heat and temperature among physics students introduction : *Procedia Social and Behavioral Sciences*, *12*, 600–614. https://doi.org/10.1016/j.sbspro.2011.02.074

Andersson, B., & Kärrqvist, C. (1983). How Swedish pupils, aged 12-15 years, understand light and its properties. *European Journal of Science Education*, *5*(4), 387–402. https://doi.org/10.1080/0140528830050403

Arends, R. I. (2012). *Learning to Teach* (9th ed.). McGraw-Hill. http://onlinelibrary.wiley.com/doi/10.1002/cbdv.200490137/abstract

Aykutlu, I., Bezen, S., & Bayrak, C. (2015). Teacher opinions about the conceptual challenges experienced in teaching physics curriculum topics. *Procedia - Social and Behavioral Sciences*, *174*, 390–405. https://doi.org/10.1016/j.sbspro.2015.01.681

Battelle for Kids. (2019). Framework for 21st century learning. In *Partnership for 21st century learning*. http://static.battelleforkids.org/documents/p21/P21_Framework_Brief.pdf

Bayraktar, S. (2009). Misconceptions of Turkish pre-service teachers about force and motion. *International Journal of Science and Mathematics Education*, *7*, 273–291.

Bell, R. L., & Trundle, K. C. (2008). The use of a computer simulation to promote scientific conceptions of moon phases. *Journal of Research in Science Teaching*, *45*(3), 346–372. https://doi.org/10.1002/tea

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., & Rumble, M. (2012). Defining twenty-first century skills. In *Assessment and Teaching of 21st Century Skills* (pp. 17–66). Springer Science+Business Media. https://doi.org/10.1007/978-94-017-9395-7

Boujaoude, S. B. (1991). A study of the nature of students' understandings about the concept of burning. *Journal of Research in Science Teaching, 28*(8), 689–704. https://doi.org/10.1002/tea.3660280806

Brna, P. (1987). Confronting dynamics misconceptions. *Instructional Science*, *16*(4), 351–379. https://doi.org/10.1007/BF00117752

Çepni, S. (2010). Computer supported conceptual change text: Fluid pressure. *Procedia Social and Behavioral Sciences, 2*, 922–927. https://doi.org/10.1016/j.sbspro.2010.03.127

Chambers, S. K., & Andre, T. (1997). Gender, prior knowledge, interest, and experience in electricity and conceptual change text manipulations in learning about direct current. *Journal of Research in Science Teaching*, *34*(2), 107–123. https://doi.org/10.1002/(SICI)1098-2736(199702)34:2<107::AID-TEA2>3.0.CO;2-X

Chang, H. P., Chen, J. Y., Guo, C. J., Chen, C. C., Chang, C. Y., Lin, S. H., … Tseng, Y. T. (2007). Investigating primary and secondary student's learning of physics concepts in Taiwan. *International Journal of Science Education*, *29*(4), 465–482. https://doi.org/10.1080/09500690601073210

Chen, C., Sonnert, G., Sadler, P. M., Sasselov, D., & Fredericks, C. (2019). The impact of student misconceptions on student persistence in a MOOC. *Journal of Research in Science Teaching,* 1–32. https://doi.org/10.1002/tea.21616

Chi, M. T. H., & Roscoe, R. D. (2002). The processes and challenges of conceptual change. In M. Limón & L. Mason (Eds.), *Reconsidering Conceptual Change: Issues in Theory and Practice* (pp. 3–28). Kluwer Academic Publishers.

Clement, J., Brown, D. E., & Zietsman, A. (1989). Not all preconceptions are misconceptions: Finding'anchoring conceptions' for grounding instruction on students' intuitions. *International Journal of Science Education*, *11*(5), 554–565. https://doi.org/10.1080/0950069890110507

Colin, P., Chauvet, F., & Viennot, L. (2002). Reading images in optics: Students' difficulties and teachers' views. *International Journal of Science Education, 24*(3), 313–332. https://doi.org/10.1080/09500690110078923

De Jong, T., & Van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research, 68*(2), 179–201. https://doi.org/10.3102/00346543068002179

Dole, J. A., & Sinatra, G. M. (1998). Reconceptualizing change in the cognitive construction of knowledge. *Educational Psychologist*, *33*(3), 109–128. https://doi.org/10.1207/s15326985ep3302&3_5

Driver, R., & Easley, J. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education, 5*(1), 61–84. https://doi.org/10.1080/03057267808559857

Erman, E. (2017). Factors contributing to students' misconceptions in learning covalent bonds. *Journal of Research in Science Teaching*, *54*(4), 520–537. https://doi.org/10.1002/tea.21375

Fazio, C., & Battaglia, O. R. (2018). Conceptual understanding of Newtonian mechanics through cluster analysis of FCI student answers. *International Journal of Science and Mathematics Education*, *17*, 1497–1517. https://doi.org/10.1007/s10763-018-09944-1

Fisher, D., & Frey, N. (2007). *Checking for understanding: formative assessment techniques for your classroom*. Association for Supervision and Curriculum Development (ASCD).

Franco, G. M., Muis, K. R., Kendeou, P., Ranellucci, J., Sampasivam, L., & Wang, X. (2012). Examining the influences of epistemic beliefs and knowledge representations on cognitive processing and conceptual change when learning physics. *Learning and Instruction*, *22*(1), 62–77. https://doi.org/10.1016/j.learninstruc.2011.06.003

Gaigher, E. (2014). Questions about answers : Probing teachers' awareness and planned remediation of learners' misconceptions about electric circuits. *African Journal of Research in Mathematics, Science and Technology Education, 18*(2), 176–187. https://doi.org/10.1080/10288457.2014.925268

Gibson, D., & Baek, Y. (Eds.). (2009). *Digital simulations for improving education: Learning through artificial teaching environments*. Information Science Reference. https://doi.org/10.4018/978-1-60566-322-7

Goldberg, F. M., & Mcdermott, L. C. (1986). Student difficulties in understanding image formation by a plane mirror. *The Physics Teacher, 24*, 472. https://doi.org/10.1119/1.2342096

Goldberg, F. M., & McDermott, L. C. (1987). An investigation of student understanding of the real image formed by a converging lens or concave mirror. *American Journal of Physics, 55*(2), 108–119. https://doi.org/10.1119/1.15254

Gomez-Zwiep, S. (2008). Elementary teachers' understanding of students' science misconceptions: Implications for practice and teacher education. *Journal of Science Teacher Education, 19*(5), 437–454. https://doi.org/10.1007/s10972-008-9102-y

Gomez, P. J. S. (2016). Students' ideas and radical constructivism. *Science & Education, 25*, 629–650. https://doi.org/10.1007/s11191-016-9829-3

Gönen, S. (2008). A study on student teachers' Misconceptions and scientifically acceptable conceptions about mass and gravity. *Journal of Science Education and Technology, 17*(1), 70–81. https://doi.org/10.1007/s10956-007-9083-1

Greca, I. M., & Moreira, M. A. (2002). Mental, physical, and mathematical models in the teaching and learning of physics. *Science Education, 86*(1), 106–121. https://doi.org/10.1002/sce.10013

Griffard, P. B., & Wandersee, J. H. (2001). The two-tier instrument on photosynthesis: What does it diagnose? *International Journal of Science Education, 23*(10), 1039–1052. https://doi.org/10.1080/09500690110038549

Guzzetti, B. J., Williams, W. O., Skeels, S. A., & Wu, S. M. (1997). Influence of text structure on learning counterintuitive physics concepts. *Journal of Research in Science Teaching, 34*(7), 701–719.

Halim, A., Lestari, D., & Mustafa. (2019). Identification of the causes of misconception on the concept of dynamic electricity. *J. Phys.: Conf. Ser., 1280*, 052060. https://doi.org/10.1088/1742-6596/1280/5/052060

Harlen, W. (2001). *Teaching, learning and assessing science 5-12*. Paul Chapman Publishing Ltd.

Helm, H. (1980). Misconceptions in physics amongst South African students. *Physics Education, 15*(2), 92–105. https://doi.org/10.1088/0031-9120/15/2/308

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher, 30*(March), 141–158.

Ilyas, A., & Saeed, M. (2018). Exploring teachers' understanding about misconceptions of secondary grade chemistry students. *International Journal for Cross-Disciplinary Subjects in Education, 9*(1), 3323–3328. https://doi.org/10.20533/ijcdse.2042.6364.2018.0444

Januszewski, A., & Molenda, M. (2008). *Educational technology: A definition with commentary*. Taylor & Francis Group.

Jenkins, E. W. (2000). Constructivism in school science education: Powerful model or the most dangerous intellectual tendency? *Science & Education, 9*, 599–610.

Kaltakci-gurel, D., Eryilmaz, A., & Mcdermott, L. C. (2017). Development and application of a four-tier test to assess pre-service physics teachers' misconceptions about geometrical optics. *Research in Science & Technological Education, 35*(2), 238–260. https://doi.org/10.1080/02635143.2017.1310094

Kaltakci-Gurel, D., Eryilmaz, A., & McDermott, L. C. (2015). A review and comparison of diagnostic instruments to identify students' misconceptions in science. *Eurasia Journal of Mathematics, Science and Technology Education, 11*(5), 989–1008. https://doi.org/10.12973/eurasia.2015.1369a

Kang, H., Scharmann, L. C., Kang, S., & Noh, T. (2010). Cognitive conflict and situational interest as factors influencing conceptual change. *International Journal of Environmental and Science Education, 5*(4), 383–405.

Kaniawati, I., Fratiwi, N. J., Danawan, A., & Suyana, I. (2019). Analyzing students' misconceptions about Newton's laws through four-tier Newtonian test (FTNT). *Journal of Turkish Science Education*, *16*(1), 110–122. https://doi.org/10.12973/tused.10269a

Karpudewan, M., Zain, A. N. M., & Chandrasegaran, A. L. (2017). Introduction: misconceptions in science education: An overview. In M. Karpudewan, A. N. M. Zain, & A. L. Chandrasegaran (Eds.), *Overcoming Students' Misconceptions in Science* (pp. 1–8). Springer Nature.

Kele, Ö., Erta, H., Uzun, N., & Cans, M. (2010). The understanding levels of preservice teachers' of basic science concepts' measurement units and devices, their misconceptions and its causes. *Procedia Social and Behavioral Sciences*, *9*, 390–394. https://doi.org/10.1016/j.sbspro.2010.12.170

Kibirige, I., Osodo, J., & Tlala, K. M. (2014). The effect of predict-observe-explain strategy on learners' misconceptions about dissolved salts. *Mediterranean Journal of Social Sciences*, *5*(4), 300–310. https://doi.org/10.5901/mjss.2014.v5n4p300

Klammer, J. (1998). An overview of techniques for identifying, acknowledging and overcoming alternate conceptions in physics education. *Klingenstein Project Report, Teachers College-Columbia University*. http://files.eric.ed.gov/fulltext/ED423121.pdf

Knowles, M. S., Holton, E. F., & Swanson, R. A. (2005). *The adult learner: the definitive classic in adult education and human resource development* (6th ed.). Elsevier.

Kolb, D. A. (2015). *Experiential learning: Experience as the source of learning and development* (Second). Pearson Education, Inc.

Komorek, M., & Duit, R. (2004). The teaching experiment as a powerful method to develop and evaluate teaching and learning sequences in the domain of non-linear systems. *International Journal of Science Education*, *26*(5), 619–633. https://doi.org/10.1080/09500690310001614717

Konicek-Moran, R., & Keeley, P. (2015). *Teaching for Conceptual Understanding in Science*. National Science Teachers Association Press.

Krebs, R. E. (1999). *Scientific development and misconceptions through the ages: A reference guide*. Greenwood Press.

Kumandaş, B., Ateskan, A., & Lane, J. (2019). Misconceptions in biology: A meta-synthesis study of research, 2000–2014. *Journal of Biological Education*, *53*(4), 350–364. https://doi.org/10.1080/00219266.2018.1490798

Labobar, H., Setyosari, P., Degeng, I. N. S., & Dsna, W. (2017). The effect of cognitive conflict strategy to chemical conceptual change. *International Journal of Science and Research (IJSR)*, *6*(4), 2350–2352. https://doi.org/10.21275/ART20172970

Langley, D., Ronen, M., & Eylon, B. S. (1997). Light Propagation and Visual Patterns: Preinstruction Learners' Conceptions. *Journal of Research in Science Teaching*, *34*(4), 399–424. https://doi.org/10.1002/(SICI)1098-2736(199704)34:4<399::AID-TEA8>3.0.CO;2-M

Lee, M., Wu, Y., & Tsai, C. (2009). Research trends in science education from 2003 to 2007: A content analysis of publications in selected journals. *International Journal of Science Education*, *31*(15), 1999–2020. https://doi.org/10.1080/09500690802314876

Liew, C. W., & Treagust, D. F. (1995). A predict-observe-explain teaching sequence for learning about students understand of heat and expansion of liquids. *Australian Science Teachers Journal*, *41*(1), 68–81.

Martín-blas, T., Seidel, L., & Serrano-fernández, A. (2010). Enhancing force concept inventory diagnostics to identify dominant misconceptions in first-year engineering physics. *European Journal of Engineering*, *35*(6), 597–606. https://doi.org/10.1080/03043797.2010.497552

Mayer, R. E. (2002). Understanding conceptual change: A Commentary. In M. Limón & L. Mason (Eds.), *Reconsidering Conceptual Change: Issues in Theory and Practice* (pp. 101–111). Kluwer Academic Publishers.

McCloskey, M., Caramazza, A., & Green, B. (1980). Curvilinear motion in the absence of external forces: Naive beliefs about the motion of objects. *Science*, *210*(4474), 1139–1141.

Mintzes, J. J., Wandersee, J. H., & Novak, J. D. (Eds.). (2005). *Assessing science understanding: A human constructivist view*. Elsevier Academic Press.

Moodley, K., & Gaigher, E. (2019). Teaching electric circuits: Teachers' perceptions and learners' misconceptions. *Research in Science Education*, *49*, 73–89. https://doi.org/10.1007/s11165-017-9615-5

National Research Council. (1997). *Science teaching reconsidered: A handbook*. The National Academies Press. https://doi.org/https://doi.org/10.17226/5287

National Research Council. (2011). *Learning science through computer games and simulations*. (M. A. Honey & M. Hilton, Eds.). The National Academies Press. https://doi.org/10.1111/j.1467-8535.2011.01247_6.x

Neidorf, T., Arora, A., Erberber, E., & Tsokodayi, Y. (2020). *Student misconceptions and errors in physics and mathematics: Exploring data from TIMSS and TIMSS*. Springer. https://doi.org/10.1007/978-3-030-30188-0

Nitko, A. J., & Brookhart, S. M. (2014). *Educational assessment of students*. Pearson Education Limited.

Osborne, R. J., & Gilbert, J. K. (1980). A method for investigating concept understanding in science. *European Journal of Science Education*, *2*(3), 311–321. https://doi.org/10.1080/0140528800020311

Özkan, G. (2013). The use of conceptual change texts as class material in the teaching of " sound " in physics. *Asia-Pacific Forum on Science Learning and Teaching, 14*(1), 1–23.

Paik, S.-H., Cho, B.-K., & Go, Y.-M. (2007). Korean 4- to 11-year-old student conceptions of heat and temperature. *Journal of Research in Science Teaching, 44*(2), 284–302. https://doi.org/10.1002/tea

Palacios, F. J. P., Cazorla, F. N., & Madrid, A. C. (1989). Misconceptions on geometric optics and their association with relevant educational variables. *International Journal of Science Education*, *11*(3), 273–286. https://doi.org/10.1080/0950069890110304

Pesman, H., & Eryilmaz, A. L. I. (2010). Development of a three-tier test to assess misconceptions about simple electric circuits. *The Journal of Educational Research*, *103*, 208–222. https://doi.org/10.1080/00220670903383002

Petty, R. E., & Cacioppo, J. T. (1986). The elaboration likelihood model of persuasion. *Advances in Experimental Social Psychology*, *19*, 123–205.

Posner, G. J., & Gertzog, W. A. (1982). The clinical interview and the measurement of conceptual change. *Science Education, 66*(2), 195–209. https://doi.org/10.1002/sce.3730660206

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a Scientific Conception: Toward a Theory of Conceptual Change. *Science Education*, *66*(2), 211–227.

Potvin, P., & Cyr, G. (2017). Toward a durable prevalence of scientific conceptions: Tracking the effects of two interfering misconceptions about buoyancy from preschoolers to science teachers. *Journal of Research in Science Teaching, 54*(9), 1121–1142. https://doi.org/10.1002/tea.21396

Prasad, B. D. (2008). Content Analysis: A Method in Social Science Research. In D. K. L. Das & V. Bhaskaran (Eds.), *Research Methods for Social Work* (pp. 173–193). Rawat Publications.

Prince, M., Vigeant, M., & Nottis, K. (2012). Development of the heat and energy concept inventory: preliminary results on the prevalence and persistence of engineering students' misconceptions. *Journal of Engineering Education, 101*(3), 412–438.

Qian, Y., Hambrusch, S., Yadav, A., Gretter, S., & Li, Y. (2019). Teachers' perceptions of student misconceptions in introductory programming. *Journal of Educational Computing Research*, (1800). https://doi.org/10.1177/0735633119845413

Ramsburg, J. T., & Ohlsson, S. (2016). Category change in the absence of cognitive conflict. *Journal of Educational Psychology, 108*(1), 98–113. https://doi.org/10.1037/edu0000050

Resbiantoro, G. (2016). Self-Efficacies of Prospective Mathematic Teachers' Technological Pedagogical Content Knowledge. *VARIDIKA (Varia Pendidikan)*, *28*(2), 102–115. http://journals.ums.ac.id/index.php/varidika/article/download/2735/1963

Resbiantoro, G., & Nugraha, A. W. (2017). Miskonsepsi Mahasiswa pada Konsep Dasar Gaya dan Gerak untuk Sekolah Dasar. *Jurnal Pendidikan Sains (JPS)*, *5*(2), 80–87. https://doi.org/10.26714/jps.5.2.2017.80-87

Ross, B., & Munby, H. (1991). Concept mapping and misconceptions: A study of high-school students' understandings of acids and bases. *International Journal of Science Education*, *13*(1), 11–23. https://doi.org/10.1080/0950069910130102

Roth, K. J. (1985). Conceptual change learning and student processing of science texts. In *American Educational Research Association*. Association of American Publishers. https://files.eric.ed.gov/fulltext/ED267980.pdf

Saunders-Stewart, K. S., Gyles, P. D. T., Shore, B. M., & Bracewell, R. J. (2015). Student outcomes in inquiry: students' perspectives. *Learning Environments Research*, *18*(2), 289–311. https://doi.org/10.1007/s10984-015-9185-2

Seatter, C. S. (2003). Constructivist science teaching: Intellectual and strategic teaching acts. *Interchange*, *34*(1), 63–87.

Seel, N. M., Lehmann, T., Blumschein, P., & Podolskiy, O. A. (2017). *Instructional design for learning*. Sense Publishers.

Singh, C. (2007). Effect of misconception on transfer in problem solving. *AIP Conference Proceedings*, *951*, 196–199. https://doi.org/10.1063/1.2820931

Skamp, K. (2012). *Teaching primary science*. Australian Academy of Science.

Slavin, R. E. (2018). *Educational Psychology: theory and practice* (Twelfth ed). Pearson.

Soeharto, Csapó, B., Sarimanah, E., Dewi, F. I., & Sabri, T. (2019). A review of students' common misconceptions in science and their diagnostic assessment tools. *Jurnal Pendidikan IPA Indonesia*, *8*(2), 247–266. https://doi.org/10.15294/jpii.v8i2.18649

Stump, D. J. (2015). *Conceptual change and the philosophy of science*. *Conceptual Change and the Philosophy of Science*. New York: Routledge. https://doi.org/10.4324/9781315712581

Taasoobshirazi, G., Sinatra, G. M., & Angeles, L. (2011). A structural equation model of conceptual change in physics. *Journal of Research in Science Teaching*, *48*(8), 901–918. https://doi.org/10.1002/tea.20434

Thagard, P. (2012). *The cognitive science of science: Explanation, discovery, and conceptual change*. The MIT Press. https://doi.org/10.7551/mitpress/9218.001.0001

Thong, W. M., & Gunstone, R. (2008). Some student conceptions of electromagnetic induction. *Research in Science Education*, *38*(1), 31–44. https://doi.org/10.1007/s11165-007-9038-9

Toh, K., Ho, B., & Chew, C. M. K. (2003). Teaching, teacher knowledge and constructivism. *Educational Research for Policy and Practice*, *2*, 195–204.

Topalsan, A. K., & Bayram, H. (2019). Identifying prospective primary school teachers' ontologically categorized misconceptions on the topic of "force and motion." *Journal of Turkish Science Education*, *16*(1), 85–108. https://doi.org/10.12973/tused.10268a

Treagust, D. (1986). Evaluating students' misconceptions by means of diagnostic multiple choice items. *Research in Science Education*, *16*, 199–207.

Treagust, D. F., Won, M., & McLure, F. (2017). Multiple Representations and Students' Conceptual Change in Science. In T. G. Amin & O. Levrini (Eds.), *Converging Perspectives on Conceptual Change*. Routledge. https://doi.org/10.4324/9781315467139

Trundle, K. C., Atwood, R. K., & Christopher, J. E. (2007). A longitudinal study of conceptual change: preservice elementary teachers' conceptions of moon phases. *Journal of Research in Science Teaching*, *44*(2), 303–326. https://doi.org/10.1002/tea

Turgut, Ü., Gürbüz, F., & Turgut, G. (2011). An investigation 10th grade students' misconceptions about electric current. *Procedia Social and Behavioral Sciences*, *15*, 1965–1971. https://doi.org/10.1016/j.sbspro.2011.04.036

Van Joolingen, W. R., & De Jong, T. (1997). An extended dual search space model of scientific discovery learning. *Instructional Science*, *25*(5), 307–346. https://doi.org/10.1023/A:1002993406499

Verkade, H., Mulhern, T. D., Lodge, Jason, M., Elliot, K., Cropper, S., Rubinstein, B. I. P., … Mulder, R. (2017). *Misconceptions as a trigger for enhancing student learning in higher educationn: A handbook for educators*. The University of Melbourne.

Vosniadou, S. (2003). Exploring the relationships between conceptual change and intentional learning. In G. M. Sinatra & P. R. Pintrich (Eds.), *Intentional conceptual change*. Lawrence Erlbaum Associates, Inc.

Vosniadou, S. (2019). The development of students' understanding of science. *Frontiers in Education*, *4*(32), 1–6. https://doi.org/10.3389/feduc.2019.00032

Wang, T., & Andre, T. (1991). Conceptual change text versus traditional text and application questions versus no questions in learning about electricity. *Contemporary Educational Psychology*, *16*, 103–116. https://doi.org/10.1016/0361-476X(91)90031-F

Weil-Barais, A. (2001). Constructivism and education: Constructivist approaches and the teaching of science. *Prospects*, *XXXI*(2), 187–196.

Widiyatmoko, A., & Shimizu, K. (2018). Literature review of factors contributing to students' misconceptions in light and optical instruments. *International Journal of Environmental and Science Education*, *13*(10), 853–863.

Wind, S. A., & Gale, J. D. (2015). Diagnostic opportunities using rasch measurement in the context of a misconceptions-based physical science assessment. *Science Education*, *99*(4), 721–741. https://doi.org/10.1002/sce.21172

Windschitl, M. (2002). Framing constructivism in practice as the negotiation of dilemmas: An analysis of the conceptual, pedagogical, cultural, and political challenges facing teachers. *Review of Educational Research*, *72*(2), 131–175.

Woolfolk, A. (2016). *Educational psychology* (13th ed.). Pearson Education.

Zacharia, Z., & Anderson, O. R. (2003). The effects of an interactive computer-based simulation prior to performing a laboratory inquiry-based experiment on students' conceptual understanding of physics. *American Journal of Physics*, *71*(6), 618–629.

Zietsman, A. I., & Hewson, P. W. (1986). Simulations and conceptual change strategies on science learning. *Journal of Research in Science Teaching*, *23*(1), 27–39.

Appendix 1

Table 1

Types of Diagnostic Tools Used by Researchers

No.	Diagnostic Tool	Researchers
1	Open-ended tests	(Aretz et al., 2016); (Çepni, 2010); (Djanette & Fouad, 2014); (Dolu & Ürek, 2015); (Durmus & Bayraktar, 2010); (Dutt & Gonzalez, 2012); (Ince & Yilmaz, 2012); (Hassane et al., 2015); (Hockicko et al., 2014); (Jafer, 2019); et al., 2013); (Martínez-Borreguero et al., 2018); (Moli et al., 2017); et al., 2007); (Ogan-Bekiroglu, 2007); (Özkan, 2013); (Periago & Bohigas, 2005); (Risch, 2014); (Shahzad & David, 2015); (Sözen & Bolat, 2011)
2	Interviews	(Abrahams et al., 2015); (Alt et al., 2011); (Aykutlu et al., 2015); (Bell & Trundle, 2008); (Kele et al., 2010); (Paik et al., 2007); (Thong & Gunstone, 2008)
3	Multiple-choice tests	(Alwan, 2011); (Bayraktar, 2009); (Bolat & Sözen, 2009); (Fazio & Battaglia, 2018); (Franco et al., 2012); ([illegible]en, 2008); (Kistner et al., 2016); (Low & Wilson, 2017); (Martín-blas et al., 2010); (Prince et al., 2012); (Schneps et al., 2014); (Taasoobshirazi et al., 2011); (Wendt & Rockinson-szapkiw, 2014); (Wind & Gale, 2015)
4	Two-tier tests	(Baser & Geban, 2007); (Chang et al., 2007); (İnce et al., 2015); (Korganci et al., 2015); (Phanphech et al., 2019); (Planinic et al., 2006); (Topalsan & Bayram, 2019)
5	Three-tier tests	(Pesman & Eryilmaz, 2010); (Taslidere, 2016); (Tunç et al., 2012); (Turgut et al., 2011)
6	Four-tier tests	(Kaltakci-gurel et al., 2017); (Kaniawati et al., 2019)
7	Sequential tests 1	(Burgoon et al., 2010); (Chantaranima & Yuenyong, 2014); (Gaigher,

		2014); (Olakanmi & Doyoyo, 2014); (Yalcin et al., 2009)
8	Sequential tests 2	(Bostan & Küçüközer, 2014)
9	Sequential tests 3	(Desstya et al., 2019); (Galili et al., 2017); (Kaya, 2014); (Lemmer et al., 2018); (Moodley & Gaigher, 2019); (Nelson et al., 2017)
10	Sequential tests 4	(Hamza & Wickman, 2008); (Trundle et al., 2007); (Falloon, 2019)

Appendix 2

Table 2

Types of Remediation Strategies Used by Researchers

No.	Remediation Strategy	Researchers
1	Simulation-Based Experiment	(Baser & Geban, 2007); (Bell & Trundle, 2008); (Dutt & Gonzalez, 2012); (Falloon, 2019); (Hockicko et al., 2014); (ince et al., 2015); (Kistner et al., 2016); (Kozhevnikov et al., 2013); (Moli et al., 2017); (Phanphech et al., 2019); (Schneps et al., 2014)
2	Conceptual Change Text	(Baser & Geban, 2007); (Çepni, 2010); (Durmus & Bayraktar, 2010); (Franco et al., 2012)
3	Inquiry-Based Learning	(Korganci et al., 2015); (Olakanmi & Doyoyo, 2014); (Trundle et al., 2007)
4	Multimedia Instruction	(Ince & Yilmaz, 2012); (Muller et al., 2007)s
5	Collaborative Learning	(Dolu & Ürek, 2015); (Wendt & Rockinson-szapkiw, 2014)
6	Model-Based Teaching	(Ogan-Bekiroglu, 2007)
7	Laboratory Experiment	(Martínez-Borreguero et al., 2018)
8	Concept Mapping	(Djanette & Fouad, 2014)

Appendix 3 (References of the 72 Reviewed Articles of Misconception in Physics)

Abrahams, I., Homer, M., Sharpe, R., & Zhou, M. (2015). A comparative cross-cultural study of the prevalence and nature of misconceptions in physics amongst English and Chinese undergraduate students. *Research in Science & Technological Education*, *33*(1), 111–130. https://doi.org/10.1080/02635143.2014.987744

Alt, Ö., Yaylac, Õ., Yamak, H., & Kavak, N. (2011). Examining pre-service science teachers' opinions about holistic approach in science: Electrical energy example. *Procedia Social and Behavioral Sciences, 15,* 2764–2770. https://doi.org/10.1016/j.sbspro.2011.04.185

Alwan, A. A. (2011). Misconception of heat and temperature among physics students Introduction : *Procedia Social and Behavioral Sciences*, *12,* 600–614. https://doi.org/10.1016/j.sbspro.2011.02.074

Aretz, S., Borowski, A., & Schmeling, S. (2016). A fairytale creation or the beginning of everything : Students' pre-instructional conceptions about the Big Bang theory. *Perspectives in Science*. https://doi.org/10.1016/j.pisc.2016.08.003

Aykutlu, I., Bezen, S., & Bayrak, C. (2015). Teacher opinions about the conceptual challenges experienced in teaching physics curriculum topics. *Procedia - Social and Behavioral Sciences*, *174*, 390–405. https://doi.org/10.1016/j.sbspro.2015.01.681

Baser, M., & Geban, Ö. (2007). Effectiveness of conceptual change instruction on understanding of heat and temperature concepts. *Research in Science and Technological Education, 25*(1), 115–133. https://doi.org/10.1080/02635140601053690

Bayraktar, S. (2009). Misconceptions of Turkish pre-service teachers about force and motion. *International Journal of Science and Mathematics Education, 7*, 273–291.

Bell, R. L., & Trundle, K. C. (2008). The use of a computer simulation to promote scientific conceptions of moon phases. *Journal of Research in Science Teaching, 45*(3), 346–372. https://doi.org/10.1002/tea

Bolat, M., & Sözen, M. (2009). Knowledge levels of prospective science and physics teachers on basic concepts on sound (sample for Samsun city). *Procedia Social and Behavioral Sciences, 1,* 1231–1238. https://doi.org/10.1016/j.sbspro.2009.01.220

Bostan, A., & Küçüközer, H. (2014). In-service science teachers' ideas about the phases of the moon and brightest star. *Procedia Social and Behavioral Sciences*, *116*, 250–255. https://doi.org/10.1016/j.sbspro.2014.01.203

Burgoon, J. N., Heddle, M. L., & Duran, E. (2010). Re-examining the similarities between teacher and student conceptions about physical science. *Journal of Science Education and Technology*, *21*, 859–872. https://doi.org/10.1007/s10972-009-9177-0

Çepni, S. (2010). Computer supported conceptual change text: Fluid pressure. *Procedia Social and Behavioral Sciences*, 2, 922–927. https://doi.org/10.1016/j.sbspro.2010.03.127

Chang, H. P., Chen, J. Y., Guo, C. J., Chen, C. C., Chang, C. Y., Lin, S. H., … Tseng, Y. T. (2007). Investigating primary and secondary student's learning of physics concepts in Taiwan. *International Journal of Science Education*, *29*(4), 465–482. https://doi.org/10.1080/09500690601073210

Chantaranima, T., & Yuenyong, C. (2014). Grade 11 students' existing ideas about natures of light. *Procedia - Social and Behavioral Sciences*, *143*, 693–697. https://doi.org/10.1016/j.sbspro.2014.07.465

Desstya, A., Program, S. E., Prasetyo, Z. K., Susila, I., & Surakarta, U. M. (2019). Developing an instrument to detect science misconception of an elementary school teacher. *International Journal of Instruction*, *12*(3), 201–218. https://doi.org/10.29333/iji.2019.12313a

Djanette, B., & Fouad, C. (2014). Determination of university students' misconceptions about light using concept maps. *Procedia - Social and Behavioral Sciences*, *152*, 582–589. https://doi.org/10.1016/j.sbspro.2014.09.247

Dolu, G., & Ürek, H. (2015). Identification and elimination of several misconceptions of university level students regarding the misconceptions in science course. *Croatian Journal of Education*, *17*(2), 353–370. https://doi.org/10.15516/cje.v17i2.888

Durmus, J., & Bayraktar, S. (2010). Effects of conceptual change texts and laboratory experiments on fourth grade students' understanding of matter and change concepts. *Journal of Science Education and Technology*, *19*, 498–504. https://doi.org/10.1007/s10956-010-9216-9

Dutt, V., & Gonzalez, C. (2012). Decisions from experience reduce misconceptions about climate change. *Journal of Environmental Psychology*, *32*(1), 19–29. https://doi.org/10.1016/j.jenvp.2011.10.003

Falloon, G. (2019). Using simulations to teach young students science concepts : An Experiential Learning theoretical analysis. *Computers & Education*, *135*, 138–159. https://doi.org/10.1016/j.compedu.2019.03.001

Fazio, C., & Battaglia, O. R. (2018). Conceptual understanding of newtonian mechanics through cluster analysis of fci student answers. *International Journal of Science and Mathematics Education*, *17*, 1497–1517. https://doi.org/10.1007/s10763-018-09944-1

Franco, G. M., Muis, K. R., Kendeou, P., Ranellucci, J., Sampasivam, L., & Wang, X. (2012). Examining the influences of epistemic beliefs and knowledge representations on cognitive processing and conceptual change when learning physics. *Learning and Instruction*, *22*(1), 62–77. https://doi.org/10.1016/j.learninstruc.2011.06.003

Gaigher, E. (2014). Questions about answers: Probing teachers' awareness and planned remediation of learners' misconceptions about electric circuits. *African Journal of Research in Mathematics, Science and Technology Education*, *18*(2), 176–187. https://doi.org/10.1080/10288457.2014.925268

Galili, I., Bar, V., & Brosh, Y. (2017). Teaching weight-gravity and gravitation in middle school: Testing a new instructional approach. *Science & Education*, *25*, 977–1010. https://doi.org/10.1007/s11191-016-9865-z

Gönen, S. (2008). A study on student teachers' Misconceptions and scientifically acceptable conceptions about mass and gravity. *Journal of Science Education and Technology*, *17*(1), 70–81. https://doi.org/10.1007/s10956-007-9083-1

Hamza, K. M., & Wickman, P.-O. (2008). Describing and analyzing learning in action: An empirical study of the importance of misconceptions in learning science. *Science Education*, *92*, 141–164. https://doi.org/10.1002/sce

Hassane, E., Talbi, M., & Radid, M. (2015). Barriers to learning physics in Moroccan secondary college: The case of student's representations in electricity. *Procedia - Social and Behavioral Sciences, 197*(February), 278–280. https://doi.org/10.1016/j.sbspro.2015.07.136

Hockicko, P., Trpisˇova, B., & Ondrus, J. (2014). Correcting students' misconceptions about automobile braking distances and video analysis using interactive program tracker. *Journal of Science Education and Technology*, *23*, 763–776. https://doi.org/10.1007/s10956-014-9510-z

İnce, E., Özsoy, Z., Yaman, Y., Gülay, F., & Yolcu, Ö. (2015). The effectiveness of the iuvirlab on undergraduate students' understanding of some physics concepts. *Procedia - Social and Behavioral Sciences*, *195*, 1785–1792. https://doi.org/10.1016/j.sbspro.2015.06.382

Ince, E., & Yilmaz, O. (2012). The usage of alternative assessment techniques in determination of misconceptions about electromagnetic field-magnetism contents and effects of video-based experiments on pre- services' achievement. *Procedia Social and Behavioral Sciences*, *55*, 206–211. https://doi.org/10.1016/j.sbspro.2012.09.495

Jafer, Y. J. (2019). Assessing kuwaiti pre-service science teachers' greenhouse effect perceptions and misconceptions. *International Journal of Science and Mathematics Education*. https://doi.org/10.1007/s10763-019-09992-1

Kaltakci-gurel, D., Eryilmaz, A., & Mcdermott, L. C. (2017). Development and application of a four-tier test to assess pre-service physics teachers' misconceptions about geometrical optics. *Research in Science & Technological Education*, *35*(2), 238–260. https://doi.org/10.1080/02635143.2017.1310094

Kaniawati, I., Fratiwi, N. J., Danawan, A., & Suyana, I. (2019). Analyzing students' misconceptions about Newton's laws through four-tier Newtonian test (FTNT). *Journal of Turkish Science Education*, *16*(1), 110–122. https://doi.org/10.12973/tused.10269a

Kaya, S. (2014). Understanding of basic science concepts: Does taking more science courses matter? *Procedia - Social and Behavioral Sciences*, *116*, 152–157. https://doi.org/10.1016/j.sbspro.2014.01.184

Kele, Ö., Erta, H., Uzun, N., & Cans, M. (2010). The understanding levels of preservice teachers' of basic science concepts' measurement units and devices, their misconceptions and its causes. *Procedia Social and Behavioral Sciences*, *9*, 390–394. https://doi.org/10.1016/j.sbspro.2010.12.170

Kistner, S., Vollmeyer, R., Burns, B. D., & Kortenkamp, U. (2016). Model development in scientific discovery learning with a computer-based physics task. *Computers in Human Behavior*, *59*, 446–455. https://doi.org/10.1016/j.chb.2016.02.041

Korganci, N., Miron, C., Dafinei, A., & Antohe, S. (2015). The Importance of Inquiry-Based Learning on Electric Circuit Models for Conceptual Understanding. *Procedia - Social and Behavioral Sciences, 191*, 2463–2468. https://doi.org/10.1016/j.sbspro.2015.04.530

Kozhevnikov, M., Gurlitt, J., & Kozhevnikov, M. (2013). Learning Relative Motion Concepts in Immersive and Non-immersive Virtual Environments. *Journal of Science Education and Technology*, *22*, 952–962. https://doi.org/10.1007/s10956-013-9441-0

Lemmer, M., Kriek, J., & Erasmus, B. (2018). Analysis of students' conceptions of basic magnetism from a complex systems perspective. *Research in Science Education*. https://doi.org/10.1007/s11165-018-9693-z

Low, D., & Wilson, K. (2017). Weight, the normal force and Newton's third law : Dislodging a deeply embedded misconception. *Teaching Science*, *63*(2), 17–26.

Martín-blas, T., Seidel, L., & Serrano-fernández, A. (2010). Enhancing force concept inventory diagnostics to identify dominant misconceptions in first-year engineering physics. *European Journal of Engineering*, *35*(6), 597–606. https://doi.org/10.1080/03043797.2010.497552

Martínez-Borreguero, G., Naranjo-Correa, F. L., Canada, F. C., Gomez, D. G., & Martín, J. S. (2018). The influence of teaching methodologies in the assimilation of density concept in primary teacher trainees. *Heliyon, 4*(11), 1–12. https://doi.org/10.1016/j.heliyon.2018.e00963

Moli, L., Delserieys, A. P., Impedovo, M. A., & Castera, J. (2017). Learning density in Vanuatu high school with computer simulation : Influence of different levels of guidance. *Education and Information Technologies*, *22*, 1947–1964. https://doi.org/10.1007/s10639-016-9527-4

Moodley, K., & Gaigher, E. (2019). Teaching electric circuits: teachers' perceptions and learners' misconceptions. *Research in Science Education*, *49*, 73–89. https://doi.org/10.1007/s11165-017-9615-5

Muller, D. A., Sharma, M. D., Eklund, J., & Reimann, P. (2007). Conceptual change through vicarious learning in an authentic physics setting. *Instructional Science*, *35*(6), 519–533. https://doi.org/10.1007/s11251-007-9017-6

Nelson, K. G., Mckenna, A. F., Brem, S. K., Hilpert, J., Husman, J., & Pettinato, E. (2017). Students' misconceptions about semiconductors and use of knowledge in simulations. *Journal of Engineering Education*, *106*(2), 218–244. https://doi.org/10.1002/jee.20163

Ogan-Bekiroglu, F. (2007). Effects of model-based teaching on pre-service physics teachers' conceptions of the Moon, Moon phases, and other lunar phenomena. *International Journal of Science Education*, *29*(5), 555–593. https://doi.org/10.1080/09500690600718104

Olakanmi, E. O., & Doyoyo, M. (2014). Using structured examples and prompting reflective questions to correct misconceptions about thermodynamic concepts. *European Journal of Engineering*, *39*(2), 157–187. https://doi.org/10.1080/03043797.2013.833177

Özkan, G. (2013). The use of conceptual change texts as class material in the teaching of "sound" in physics. *Asia-Pacific Forum on Science Learning and Teaching*, *14*(1), 1–23.

Paik, S.-H., Cho, B.-K., & Go, Y.-M. (2007). Korean 4- to 11-year-old student conceptions of heat and temperature. *Journal of Research in Science Teaching*, *44*(2), 284–302. https://doi.org/10.1002/tea

Periago, M. C., & Bohigas, X. (2005). A study of second-year engineering students' alternative conceptions about electric potential, current intensity and Ohm's law. *European Journal of Engineering Education*, *30*(1), 71–80. https://doi.org/10.1080/03043790410001711225

Pesman, H., & Eryilmaz, A. L. I. (2010). Development of a three-tier test to assess misconceptions about simple electric circuits. *The Journal of Educational Research*, *103*, 208–222. https://doi.org/10.1080/00220670903383002

Phanphech, P., Tanitteerapan, T., & Murphy, E. (2019). Explaining and enacting for conceptual understanding in secondary school physics. *Issues in Educational Research*, *29*(1), 180–205.

Planinic, M., Boone, W. J., Krsnik, R., & Beilfuss, M. L. (2006). Exploring alternative conceptions from Newtonian dynamics and simple DC circuits: Links between item difficulty and item confidence. *Journal of Research in Science Teaching*, *43*(2), 150–171. https://doi.org/10.1002/tea.20101

Prince, M., Vigeant, M., & Nottis, K. (2012). Development of the heat and energy concept inventory: Preliminary results on the prevalence and persistence of engineering students' misconceptions. *Journal of Engineering Education*, *101*(3), 412–438.

Risch, M. R. (2014). Investigation about representations used in teaching to prevent misconceptions regarding inverse proportionality. *International Journal of STEM Education*, *1*(4), 1–7.

Schneps, M. H., Ruel, J., Sonnert, G., Dussault, M., Grif, M., & Sadler, P. M. (2014). Conceptualizing astronomical scale: Virtual simulations on handheld tablet computers reverse misconceptions. *Computers & Education*, *70*, 269–280. https://doi.org/10.1016/j.compedu.2013.09.001

Shahzad, G., & David, S. (2015). Effects of conceptual, procedural, and declarative reflection on students' structural knowledge in physics. *Educational Technology Research and Development*, *63*, 185–201. https://doi.org/10.1007/s11423-015-9368-7

Sözen, M., & Bolat, M. (2011). Determining the misconceptions of primary school students related to sound transmission through drawing. *Procedia Social and Behavioral Sciences*, *15*, 1060–1066. https://doi.org/10.1016/j.sbspro.2011.03.239

Taasoobshirazi, G., Sinatra, G. M., & Angeles, L. (2011). A structural equation model of conceptual change in physics. *Journal of Research in Science Teaching*, *48*(8), 901–918. https://doi.org/10.1002/tea.20434

Taslidere, E. (2016). Development and use of a three-tier diagnostic test to assess high school students' misconceptions about the photoelectric effect. *Research in Science & Technological Education*, *34*(2), 164–186. https://doi.org/10.1080/02635143.2015.1124409

Thong, W. M., & Gunstone, R. (2008). Some student conceptions of electromagnetic induction. *Research in Science Education*, *38*(1), 31–44. https://doi.org/10.1007/s11165-007-9038-9

Topalsan, A. K., & Bayram, H. (2019). Identifying prospective primary school teachers' ontologically categorized misconceptions on the topic of "Force and Motion." *Journal of Turkish Science Education*, *16*(1), 85–108. https://doi.org/10.12973/tused.10268a

Trundle, K. C., Atwood, R. K., & Christopher, J. E. (2007). A longitudinal study of conceptual change: Preservice elementary teachers' conceptions of moon phases. *Journal of Research in Science Teaching*, *44*(2), 303–326. https://doi.org/10.1002/tea

Tunç, T., Çam, H. K., & Dökme, İ. (2012). A study on misconceptions of senior class students in some physics topics and the effect of the technique used in misconception studies. *Journal of Turkish Science Education*, *9*(3), 154–160.

Turgut, Ü., Gürbüz, F., & Turgut, G. (2011). An investigation 10th grade students' misconceptions about electric current. *Procedia Social and Behavioral Sciences*, *15*, 1965–1971. https://doi.org/10.1016/j.sbspro.2011.04.036

Wendt, J. L., & Rockinson-szapkiw, A. (2014). The effect of online collaboration on middle school student science misconceptions as an aspect of science literacy. *Journal of Research in Science Teaching*, *51*(9), 1103–1118. https://doi.org/10.1002/tea.21169

Wind, S. A., & Gale, J. D. (2015). Diagnostic opportunities using Rasch measurement in the context of a misconceptions-based physical science assessment. *Science Education*, *99*(4), 721–741. https://doi.org/10.1002/sce.21172

Yalcin, M., Altun, S., Turgut, U., & Aggu, F. (2009). First year Turkish SCIENCE undergraduates' understandings and misconceptions of light. *Science & Education*, *18*(1), 1083–1093. https://doi.org/10.1007/s11191-008-9157-3

Zhu, Y., Zhang, L., Leng, Y., Pang, R., & Wang, X. (2019). Event-related potential evidence for persistence of an intuitive misconception about electricity. *Mind, Brain, and Education*, *13*(2), 1–12. https://doi.org/10.1111/mbe.12188

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