International Journal of Elementary Education
Volume 8, Number 1, Tahun 2024, pp. 57-69
P-ISSN: 2579-7158 E-ISSN: 2549-6050
Open Access: https://doi.org/10.23887/ijee.v8i1.68967

Diagnosing Elementary School Students' Representation of Light Concept Through the Five-tier Diagnostic Test

Yogi Kuncoro Adi[1*], Ari Widodo[2], Wahyu Sopandi[3], Muslim[4]

[1,3] Elementary Education, Universitas Pendidikan Indonesia, Bandung, Indonesia
[2] Science Education, Universitas Pendidikan Indonesia, Bandung, Indonesia
[4] Physics Education, Universitas Pendidikan Indonesia, Bandung, Indonesia

ARTICLE INFO

Article history:
Received October 10, 2023
Accepted January 20, 2024
Available online February 25, 2024

Kata Kunci:
Tes Diagnostik Lima Tingkat, Representasi, Konsep Cahaya, Sekolah Dasar

Keywords:
Five-tier Diagnostic Test, Representation, Light Concepts, Elementary School

ABSTRAK

Siswa sekolah dasar belum memiliki pemahaman yang ilmiah mengenai konsep cahaya. Misalnya, mereka merepresentasikan penglihatan sebagai proses benda yang terkena cahaya dan mata secara otomatis mampu melihatnya. Baik representasi verbal maupun visual mereka menunjukkan ketidaksesuaian terhadap keyakinan ilmiah. Penting bagi siswa untuk memahami sains secara lebih komprehensif melalui pembelajaran multi representasi. Tes diagnostik yang relevan diperlukan untuk mengetahui profil multi representasi siswa. Namun, tes diagnostik yang digunakan untuk mengidentifikasi profil multi representasi siswa sekolah dasar masih jarang ditemukan. Paper ini bertujuan untuk mengomunikasikan hasil pengembangan, validitas, dan reliabilitas, serta uji coba terhadap five-tier diagnostic test (5TDT) dalam mengukur multi representasi siswa sekolah dasar mengenai konsep cahaya. Ini adalah versi pengembangan dari four-tier yang mana ada pilihan jawaban dan alasannya serta tingkat keyakinan siswa dalam menjawab keduanya. Paket berjumlah 15 soal dikembangkan lalu diuji keterbacaan oleh guru dan siswa sekolah dasar kemudian diujicobakan. Sejumlah 227 siswa sekolah dasar yang telah mempelajari konsep cahaya mencoba tes ini. Validitas internal diserahkan kepada lima expert dan menunjukkan hasil yang valid dengan beberapa catatan perbaikan. Sementara, hasil uji statistik pada validitas eksternal dan reliabilitas menunjukkan bahwa five-tier diagnostic test valid dan reliabel. Five-tier diagnostic test dapat mengukur keragaman representasi siswa mengenai konsep cahaya dengan lebih presisi. Hal ini terlihat dari mereka mendominasi pada tingkat Lack of Representation (LOR) sebesar 39% dan Misconception (MIS) sebesar 31%.

ABSTRACT

Elementary school students do not yet have a scientific understanding of light. For example, they represent vision as the process of objects being hit by light and the eye being automatically able to see them. Their verbal and visual representations present irrelevance to scientific beliefs. Students need to understand science more comprehensively through multiple-representation learning. The relevant diagnostic tests are needed to find out student multiple-representation profiles. However, diagnostic tests identifying multiple-representation profiles of elementary school students are still rare. This paper aims to communicate the results of development, validity, and reliability, as well as trials of the five-tier diagnostic test (5TDT) in measuring multiple representations of elementary school students about light concepts. The 5TDT is a developed version of the four-tier where there are answer choices and reasons and the level of student confidence in answering both. A package of 15 questions was developed, tested for readability by elementary school teachers and students, and then piloted. Two hundred twenty-seven elementary school students who had studied the concept of light attempted this test. Internal validity was submitted to five experts and showed valid results with several improvement notes. Meanwhile, the results of statistical tests on external validity and reliability show that the five-tier diagnostic test is valid and reliable. The five-tier diagnostic test can measure the diversity of students' representation of their ideas regarding the light concept with more precision. It is shown that they are dominating the Lack of Representation (LOR) level of 39% and Misconception (MIS) level of 31%.

1. INTRODUCTION

Science learning is how students understand and apply various scientific concepts and methods concretely in their daily lives, making it easier for them to learn a concept (Kelana, Robandi, & Widodo, 2022; Masfuah et al., 2021). Therefore, teachers have a role in instructing and training students' knowledge structures during the knowledge construction process to make meaning-making (Dikmenli, 2010; Jampel et al., 2018). A student who actively constructs knowledge about various phenomena during his life without the participation of a teacher often has a different view from scientists. So, teachers must be able to distinguish the characteristics of students who lack knowledge, misconceptions, or other profiles to overcome problems by designing learning as a solution (Juita et al., 2023; Kartimi et al., 2021; Köse, 2008;

*Corresponding author.
E-mail addresses: yogikuncoroadi@upi.edu (Yogi Kuncoro Adi)

Margunayasa et al., 2021; Putri, Widodo, & Rusyati, 2021; Resbiantoro, Setiani, & Dwikoranto, 2022; Soeharto et al., 2019). In the case of misconceptions, for example, a student with this case is still an obstacle and tends to resist change when this problem continues in various learning and concepts (Dikmenli, 2010; Kartimi et al., 2021). Learning new concepts will be difficult for students to accept because they consider the conceptions they have believed to be scientific (Mubarak & Yahdi, 2020). For example, learning the concept of optics will be difficult before students finish the light concept. Learning based on the representation level can provide students with conceptual understanding so that misconceptions can be reduced (Banawi et al., 2022; Cahyanto, Ashadi, & Saputro, 2019).

Literature analysis shows that learning in schools often requires students to use various modes to create representations of their science knowledge (Hoban, Loughran, & Nielsen, 2011; Park, Tang, & Chang, 2021; Wilson & Bradbury, 2021). Multiple representations are used with students and by students in representing a concept in various forms of representation, which are integrated rather than separate. The forms can be analogies, verbal explanations, written texts, diagrams, graphs, or simulations (Tang, Delgado, & Moje, 2014). Students must understand the relationships between representations, but they tend to understand representations separately, making it difficult to integrate information from more than one source (Ainsworth, 2006). This transformation of students in representing a concept into various formats creates a challenge for teachers (Syahmel & Jumadi, 2019). The problem at school is that in science lessons, students master different representations. Understanding this problem is important, so it requires an assessment that integrates various types of representation (Anam et al., 2019; Asriadi & Istiyono, 2022; Dirman, Mufit, & Festiyed, 2022). The explanation is that the identification of verbal representations is assisted by questions that ask students to explain a concept through verbal sentences. In contrast, pictorial representations ask them to create visualizations. The problem is that there are still very few assessments that combine these various modes of representation in one format, especially in instruments that diagnose representations of the concept of light.

Regarding the concept of light, this concept was chosen because it is an important concept taught in elementary school because it closely relates to everyday life. This topic was also chosen because there are findings that lead to the identification of unscientific representations from time to time, such as in the case of the seeing process, students assume that a light source is enough in the seeing process or just the eyes are enough, the light from the light source moves to the eyes and then the light is reflected onto an object so that the object can be seen, or the light hits the eye and then reflects in another direction, and elementary school children emphasize the function of each component and not the process (Uzun, Alev, & Karal, 2013; Xu, Prain, & Speldewinde, 2021). Meanwhile, the origin of the scientific picture regarding the process of how the eye sees was proposed by Ibn al-Haytham in the 13th century AD, where he stated that light propagates directly from the source to the object, and some of it is transmitted in various directions, including towards our eyes. Some basic characteristics of light, such as these, should be explained as part of knowledge in elementary school (Kokologiannaki & Ravanis, 2012). Students will comprehensively master the concept of light through multiple representations. The forms of representation that correspond to the material characteristics of light are verbal, visual, and mathematical (Fatimah, 2016; Prain & Hand, 2016). However, in the case of research in elementary schools, verbal descriptions of light problems were transferred into pictorial form, or vice versa, and had not yet reached mathematical mastery.

This type of diagnostic test is commonly used in learning assessments in the Kurikulum Merdeka because it is intended to identify students' strengths and weaknesses so that learning can be adjusted to their abilities (Harfiani & Desstya, 2023). Teachers must effectively identify students' science learning difficulties at the beginning of learning (Akkus, Kadayifci, & Atasoy, 2011; Dewi, Lidyawati, & Destiansari, 2022). So, there is a need for more valid and reliable assessment techniques for students' conceptual understanding (Aydeniz, Bilican, & Kirbulut, 2017; Lim & Poo, 2021). Interviews, open-ended or free-response questionnaires, word associations, multiple-choice tests, and multiple-tier tests with two-tiers, three-tiers, and four-tiers are the most commonly used diagnostic instruments to diagnose students' conceptions of science (Kaltakci-Gurel, Eryilmaz, & McDermott, 2017). Apart from that, instruments such as concept mapping, prediction-observation-explanation, and images can be used (Köse, 2008). Researchers and teachers must understand the advantages and disadvantages of each type of diagnostic test in order to choose the most effective instrument according to their objectives. Therefore, identifying students' prior knowledge must be done before learning because diagnosis aims to improve learning.

Multiple tier-test are a type of diagnostic test that is becoming trendy and is effectively used to identify students' science learning difficulties (Anam et al., 2019; Fajriyyah & Ermawati, 2020; Juliani, Yusrizal, & Huda, 2021; Resbiantoro et al., 2022; Soeharto et al., 2019). Diagnostic tests with several levels were developed to overcome the weaknesses of other diagnostic tests. Our consideration of various types of multiple tier-diagnostic tests is presented as an argument for choosing the best one.

The first tier-test is a type of multiple choice test (MCT) with one correct answer choice and two or more wrong choices as distractors (Aydeniz et al., 2017). The advantages of this type of test are that it is easy to measure the understanding of a large number of students, more time efficient in analyzing answers, and a more objective assessment. Meanwhile, the weaknesses are not being able to investigate students' ideas in depth due to limited patterns of diagnosed conceptual understanding, there are correct answers even though they are only guesses, difficulty in compiling appropriate items, students cannot openly fill in the answer choices they want (Caleon & Subramaniam, 2010; Fajriyyah & Ermawati, 2020; Resbiantoro et al., 2022; Schultz et al., 2017).

The second tier-test is a two-tier diagnostic test (2TDT), with the first tier being multiple choice questions about concepts and the second tier being the reasons for the first tier answers. Students are considered to have a scientific conception if they choose the correct answer and reason (Widiyatmoko & Shimizu, 2018). The reasons for the answers at the second tier were developed based on student conception interviews and recent research findings (Schultz et al., 2017). As an alternative to MCT, 2TDT is effective in better diagnosing students' conceptions because it measures students choosing answers correctly and the reasons for their choices. The 2TDT also has weaknesses, namely not being able to separate errors due to lack of knowledge from errors due to misconceptions, not being able to differentiate correct answers based on guesses from correct answers based on original understanding, and not representing students' authentic thinking because alternative answers have been prepared through answer items (Caleon & Subramaniam, 2010; Resbiantoro et al., 2022; Widiyatmoko & Shimizu, 2018).

The third tier-test is the three-tier diagnostic test (3TDT), with the first tier aiming to determine students' conceptual understanding, the second tier containing multiple choice questions to find out the conceptual reasons for the answers at the first tier, and the third tier consisting of confidence in the answers at the two previous tiers (Caleon & Subramaniam, 2010). The advantage of this type of test is that it can identify students with a profile of misconceptions and lack of knowledge because of their confidence in the answers. However, students only expressed one level of belief, but it was unclear whether this belief was directed at the answer choices at the first or second tier. This also shows its weaknesses (Caleon & Subramaniam, 2010; Çelikkanlı & Kızılcık, 2022; Resbiantoro et al., 2022).

The fourth tier-test is the four-tier diagnostic test (4TDT), with the first tier consisting of answers to questions from a concept, the second tier consisting of confidence in the answer for the first tier, the third tier consisting of reasons for the answer from the first tier, while the fourth tier consists of confidence in the answer for the third tier. In 4TDT, the level of confidence in answers is given separately for both the first tier and the third tier (Caleon & Subramaniam, 2010; Çelikkanlı & Kızılcık, 2022). The 4TDT is more valid in analyzing students' conceptions than previous tiered tests (Resbiantoro et al., 2022). The advantage of 4TDT is that it can explore various student conceptual profiles in depth and plan remediation learning with better preparation for related concepts (Kartimi et al., 2021). Meanwhile, the weakness is that it does not allow students to express their ideas in answering questions, and there is still the possibility of students guessing the answer. Therefore, an extra tier needs to be added to facilitate a more comprehensive student conception; this depends on the researcher's needs (Fajriyyah & Ermawati, 2020). Both MCT, 2TDT, 3TDT, and 4TDT have the weakness of only diagnosing students' verbal representations. We propose an extra tier that can facilitate the combination of representations, as few studies have developed this type of test. Based on the analysis of various tier-tests, researchers developed this type of diagnostic test up to the five-tier diagnostic test (5TDT). This development is motivated not only by the level of validity of the latest tiered tests but also by researchers' need to master multiple representations. We hope that our work can provide teachers perception of a new way of identifying students' multiple representation profiles with more precision.

The first four tiers of 5TDT have a format similar to 4TDT to find students' verbal representations and the fifth tier to find their visual representations. The development of 5TDT was inspired by representational analysis of the basic concepts of chemistry discipline in elementary schools (Anam et al., 2019) meanwhile, this research aims at the basic concepts of physics discipline in elementary schools. It is explained further in the paper that the design of the 5TDT is at the first tier in the form of the main question, the second tier is the level of confidence for the first tier, the third tier is the reason for the answer to the main question, the fourth tier is the level of confidence for the third tier, and the fifth tier is a drawing test or visual representation. In several previous studies, the fifth tier of 5TDT used a different format, which could be in the form of providing conclusions, drawing pictures, or determining the source of the causes of students' conceptions (Dirman et al., 2022). The advantages of 5TDT are that the five-tier questions function to reduce students' chances of guessing answers, questions are easier for students to answer, the assessment is consistent, does not take much time, can reveal various conception profiles, helps teachers in presenting representation-based learning so that students can understand concepts well, can find out the

causes of diversity in students' conceptions because images are a reflection of students' thinking, combining many instruments to collect information about students' conceptions (Anam et al., 2019; Juita et al., 2023).

Verbal and visual representation formats convey different and complementary information, which is useful in constructing deeper understanding. Usually, students organize verbal representations to be coherent and then construct, correlate, or convert visual representations based on verbal mastery of concepts (Park et al., 2020; Park et al., 2021; Wilson & Bradbury, 2021; Wiyantara, Widodo, & Prima, 2021). Drawing is a technique for exploring students' conceptions holistically and authentically (Dikmenli, 2010; Köse, 2008). Teachers can use the drawing to inform concepts from and for students because it has a role in assessment and learning simultaneously, which can be used to improve mastery of concepts. Drawing can be a learning and assessment activity that is developmentally appropriate for elementary school students because it is fun for them. Explicit learning in making scientific drawings is important for students so that their visualizations provide accurate assessment results. When used in learning, students need guidance from the teacher in making scientific drawings. Finally, it is recommended that learning and assessment through drawing be included in the science curriculum in elementary schools (Wilson & Bradbury, 2021).

The data is analyzed for multiple representations so that the level of representation profile for each student can be known. Changes in the level of representation can be explained as the level of conceptual change in students' thinking (Halverson & Friedrichsen, 2013), namely: (1) no use of representation, (2) superficial use of representation, (3) simplified use of representation, (4) symbolic use of representation, (5) conceptual use of representation, (6) scientific use of representation, and (7) expert use of representation. This level of change can also be indicated as Learning Progressions, where the representation starts from naivety to sophistication. In other research (Anam et al., 2019), there were different levels of verbal and visual representation modes. For verbal representation, we use levels consisting of SC (Scientific Conception), ASC (Almost Scientific Conception), LC (Lack of Confidence), LK (Lack of Knowledge), MSC (Misconception), and HNC (Have No Conception). Meanwhile, for visual representation, we use levels consisting of Scientific Drawing (SD), Partial Drawing (PD), Misconception Drawing (MD), Undefined Drawing (UD), Non-Microscopic Drawing (NMD), and No Drawing (ND). In addition, particular studies analyze students' levels of visual representation through drawing (Dikmenli, 2010; Köse, 2008), which include levels of No Drawing, Non-Representational Drawings, Drawings with Misconceptions, Partial Drawings, Comprehensive Representation Drawings.

Based on the background described, the research reported here aims to describe the development of 5TDT used in diagnosing elementary school students' verbal and visual representation profiles on the concept of light. In more detail, we describe the development step by step in detail, how readability, validity and reliability tests are carried out, analyze each student's answer-reasoning-drawing profile, and recommend this type of test for conceptual learning planning purposes. Researchers use the stages of developing diagnostic tests as pioneered by experts.

2. METHOD

This research describes the development of 5TDT, used to diagnose elementary school students' verbal and visual representation profiles regarding the concept of light. This background is based on suggestions for the development of diagnostic assessment tools to identify student conception profiles, namely researchers: (a) analyze concepts that are often found in students with unscientific conceptions; (b) select diagnostic tests by considering their advantages and disadvantages; and (c) combining two diagnostic tests (Soeharto et al., 2019). First, researchers analyzed various research findings to find that the concept of light is one of the many basic concepts in elementary school that many students encounter with a lack of knowledge and misconceptions. Second, we observed that 4TDT and 5TDT as current diagnostic tests have many advantages in their usefulness, and because of our need for identification of representations, we are more likely to choose 5TDT. Third, our development of the 5TDT integrates multiple-choice tests (MCT) with confidence levels and drawing tests so that the combination of these two types of tests is expected to strengthen the analysis results of our 5TDT.

The development of 5TDT in this research followed the stages of a modified version of Treagust (Caleon & Subramaniam, 2010). The important key stages in the development of 5TDT are as follows. Defining the Content Boundaries of the Study; The concept map that determines the boundaries of 5TDT development refers to Minister of Education and Culture Regulation Number 37 of 2018 at KD 3.7. Applying the properties of light and their relationship to the sense of sight, 2013 NGSS Lead States at 4-PS4-2. Develop a model to describe that light reflecting from objects and entering the eyes allows objects to be seen, and TIMSS 2019 Assessment Framework on Light and sound in everyday life: Relate familiar physical phenomena to the behavior of light. Based on this study, finally, 5TDT focuses on several sub-concepts in

the concept of light, as shown in Table 1 which include: objects can be seen, light can be reflected, light passes through transparent objects, light cannot pass through opaque objects, light can be dispersed. Exploratory Phase; Potential alternative representations are analyzed first through a review of various general findings from current research, observations of learning about the concept of light in one class, and interviews with students individually and voluntarily.

Content Validation and Piloting; We define the sub-concepts behind the development of the questions. We asked 15 elementary school students to read the questions at tier 1 (answer), 3 (reason), and 5 (drawing) and understand the meaning of readability. After revising them, we submitted them to 10 elementary school teachers to test their readability according to the teacher's perception. Some qualitative input is provided as comments on each statement and image, making it easy for 4th-grade elementary school students to understand. For example, in the opening section of tier 1, context is given close to students' lives and images that make it easier for them to imagine a phenomenon. Apart from that, at tier 5, the columns are not left blank but already contain images, and students can later provide additional ones. In the next step, we submitted our 5TDT to 5 Expert Judgments consisting of 3 Lecturers with Doctoral Degrees with Experts on Educational Assessment, Physics Education, and Science in Elementary School Education, and 2 Teachers with Master's Degrees in Elementary Education and Certified Teacher in Elementary School. Generally, the assessment results on content, construct, and language shows achievements in the very valid category in the range of 81-100 (Riduwan & Akdon, 2020). Finally, this study tested 5TDT on 227 students from 4 different elementary schools who were not included in the main study. Based on statistical validity and reliability tests, two questions were reconstructed so that they could still be used to test the main sample.

Table 1. Distribution of Sub-Concept

Indicators	Sub-Concept	Number of Questions
Indicator 1	Objects can be seen	1, 2
Indicator 2	Light can be reflected	3, 4, 5, 6, 7
Indicator 3	Light passes through transparent objects	8, 9, 10
Indicator 4	Light cannot pass through opaque objects	11, 12
Indicator 5	Light can be dispersed	13, 14, 15

Construction, Administration, and Validation; We used the pilot results to refine the 5TDT further to form the 15-item final version of this diagnostic test. The 5TDT structure in this research follows a similar development (Anam et al., 2019); namely, tier 1 is the main question (verbal representation), tier 2 is the confidence level, tier 3 is the reason for the answer (verbal representation), tier 4 is confidence level, and tier 5 in the form of drawing reasons for answers (visual representation). We create results interpretation guidelines that make it easier for us to interpret student work results. For the main sample, when giving them the 5TDT, we asked them first to fill in their student ID. They were also told that the test questions would improve learning and would not be a school assessment, so they were expected to fill in their confidence levels honestly. We always accompany students in their progress in taking tests; for example, we always remind them that tier 2 is filled in based on confidence in tier 1, and tier 4 is filled in based on confidence in tier 3. The same thing is also done in tier 3 for tier 1, that both interrelated as answers and reasons. At tier 5, we also accompany them in visualizing their ideas. This assistance is intended because students in the main sample have never worked on diagnostic test questions.

Main Sample; This paper presents a multi-representational profile of 27 4th-grade elementary school students from a suburban school regarding 5TDT, which was developed on the concept of light. Treatment of Data; students' answers are interpreted using the guidelines that have been developed. Tiers 1 and 3 are given a score of "Correct" if the student's answer is correct and "Wrong" if their answer is wrong. Tiers 2 and 4 were given a score of "Sure" if they expressed confidence and "Not Sure" if their answer did not indicate confidence. Tier 5 has its scoring because the form of the test is drawing. If their answer includes Scientific Visualization (SCV), then it can be changed to "Correct" while others are "Wrong." After that, we can interpret the final results into a multi-representation frame. The possibility of student answers and results' interpretation is presented in Table 2 and the description of students' visual representation is presented in Table 3.

Table 2. The Possibility of Student Answers and Results' Interpretation

No	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5	Decision
1	Correct	Sure	Correct	Sure	Correct	Scientific Representation (SR)
2	Correct	Sure	Correct	Sure	Wrong	Almost Scientific Representation (ASR)

No	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5	Decision
3	Correct	Sure	Correct	Not Sure	Correct	Partial Representation (PR)
4	Correct	Sure	Correct	Not Sure	Wrong	Partial Representation (PR)
5	Correct	Not Sure	Correct	Sure	Correct	Partial Representation (PR)
6	Correct	Not Sure	Correct	Sure	Wrong	Partial Representation (PR)
7	Correct	Not Sure	Correct	Not Sure	Correct	Partial Representation (PR)
8	Correct	Not Sure	Correct	Not Sure	Wrong	Partial Representation (PR)
9	Correct	Sure	Wrong	Sure	Correct	Lack of Representation (LOR)
10	Correct	Sure	Wrong	Sure	Wrong	Lack of Representation (LOR)
11	Correct	Sure	Wrong	Not Sure	Correct	Lack of Representation (LOR)
12	Correct	Sure	Wrong	Not Sure	Wrong	Lack of Representation (LOR)
13	Correct	Not Sure	Wrong	Sure	Correct	Lack of Representation (LOR)
14	Correct	Not Sure	Wrong	Sure	Wrong	Lack of Representation (LOR)
15	Correct	Not Sure	Wrong	Not Sure	Correct	Lack of Representation (LOR)
16	Correct	Not Sure	Wrong	Not Sure	Wrong	Lack of Representation (LOR)
17	Wrong	Sure	Correct	Sure	Correct	Lack of Representation (LOR)
18	Wrong	Sure	Correct	Sure	Wrong	Lack of Representation (LOR)
19	Wrong	Sure	Correct	Not Sure	Correct	Lack of Representation (LOR)
20	Wrong	Sure	Correct	Not Sure	Wrong	Lack of Representation (LOR)
21	Wrong	Not Sure	Correct	Sure	Correct	Lack of Representation (LOR)
22	Wrong	Not Sure	Correct	Sure	Wrong	Lack of Representation (LOR)
23	Wrong	Not Sure	Correct	Not Sure	Correct	Lack of Representation (LOR)
24	Wrong	Not Sure	Correct	Not Sure	Wrong	Lack of Representation (LOR)
25	Wrong	Sure	Wrong	Sure	Correct	Misconception (MIS)
26	Wrong	Sure	Wrong	Sure	Wrong	Misconception (MIS)
27	Wrong	Sure	Wrong	Not Sure	Correct	Lack of Representation (LOR)
28	Wrong	Sure	Wrong	Not Sure	Wrong	No Representation (NR)
29	Wrong	Not Sure	Wrong	Sure	Correct	Lack of Representation (LOR)
30	Wrong	Not Sure	Wrong	Sure	Wrong	No Representation (NR)
31	Wrong	Not Sure	Wrong	Not Sure	Correct	Lack of Representation (LOR)
32	Wrong	Not Sure	Wrong	Not Sure	Wrong	No Representation (NR)

Table 3. The Description of Students' Visual Representation

No	Category	Description
1	Scientific Visualization (SCV)	Students visualize concepts according to scientific and detailed conceptions
2	Simple Visualization (SIV)	Students visualize concepts almost following scientific conceptions because the images created are incomplete
3	Superficial Visualization (SUV)	Students visualize concepts with some relevance to scientific conceptions, while most others are not yet appropriate
4	Misconception (MIS)	Students visualize concepts with images that are opposite to scientific conceptions
5	Undefined Visualization (UV)	Students visualize concepts with unclear images or not relevant to any concept
6	No Visualization (NV)	Students do not visualize concepts in the image form

3. RESULT AND DISCUSSION

Result

The diversity of students' abilities in representing their ideas regarding the properties of light in Figure 1 shows that they dominate the Lack of Representation (LOR) level of 39%. Students at this level provide representations that are only correct in answers to general questions or correct in the reasons for their answers, with different levels of confidence in answering. At the same time, they achieve the results of drawing representations at varying levels. Almost the same, 31% of students are at the Misconception (MIS) level, where they are wrong in answering the main question and the reasons for the answer but have high confidence in answering both. At the Almost Scientific Representation (ASR) level, it was found to be 18%. Meanwhile, only some student profiles are still at the Scientific Representation (SR) level.

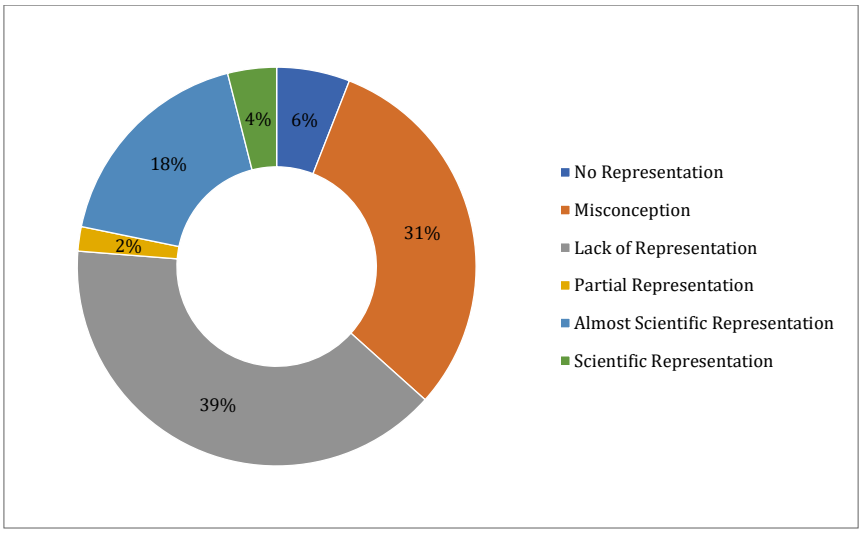

Figure 1. Percentage of Elementary School Student Representation of the Concept of Light

Findings on individual student representation profiles will illustrate individual strengths and weaknesses. Meanwhile, the group representation profile describes their strengths and weaknesses in certain subconcepts. The findings in Figure 2 show that Concept 5 Light can be dispersed, is a concept with multiple levels of representation that is the most comprehensive and difficult for students. On the other hand, Concept 1 Objects can be seen is a concept that is relatively easier for them to represent. Based on discussions between researchers and teachers, this is the first experience for students working on multiple representation diagnostic test questions, and they are still learning representations in a single format. The use of a single format of representation makes their average profile at the level of Lack of Representation (LOR) and Misconception (MIS) even across all five concepts about light.

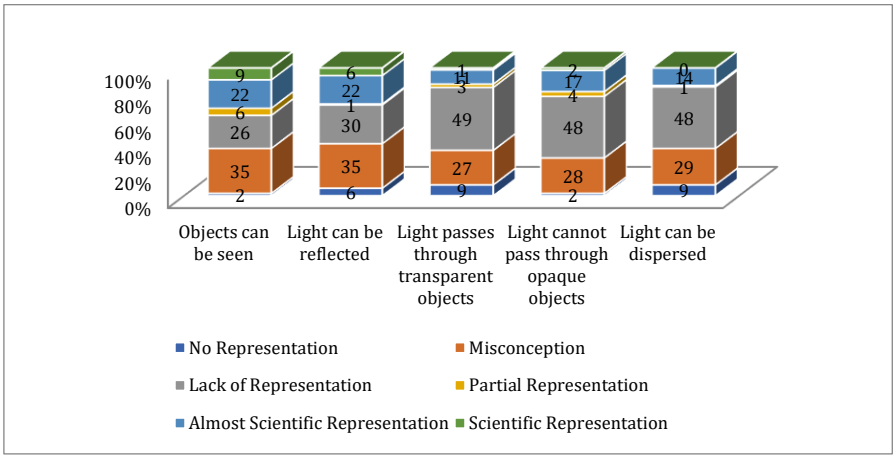

Figure 2. Percentage of Elementary School Student Representation of the Sub-Concept of Light

From one sample of student representations regarding Seeing an Object, we describe how to analyze their profiles more deeply. In the analysis of the answers-reasons from the students' verbal representations, a path connecting their profiles is created. Here, students answer consistently scientifically or unscientifically, but sometimes progress or regress, and sometimes even inconsistent or random. In the sub-concept of Light hitting objects, students have various verbal representations regarding Seeing an Object. Cases of students' verbal representations based on the findings can be divided into seven types: (1) Students understand that when there is no light, objects of any color cannot be seen by the eye. The vision process is that light hits the object and then reflects the direction of the light reflection to the eye; (2) Students understand that when there is no light, objects of any color cannot be seen by the eye, the vision process is when the color of the object shines and then propagate towards the eye; (3) Students assume that brightly colored objects are sources of light, so that colored light will be directed to the eyes; (4) Students assume that brightly colored objects are a source of light, the colored light will hit other objects and the reflection will lead to the eyes; (5) Students assume that bright colored objects are a source of light, and so

are the eyes, so that the process of seeing occurs; (6) Students mentioned that a person's eyes can function optimally even when there is no light, but the color of objects will shine through and help vision become clearer; and (7) Students stated that a person's eyes can function optimally even in the absence of light, but vision will be clearer when there is light hitting an object and its reflection is directed towards the eye. Figure 3 presents students and their percentages when choosing answers and providing arguments for their answers.

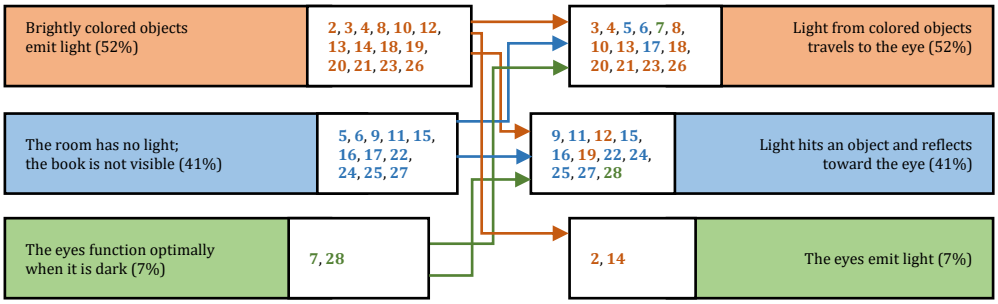

Figure 3. Verbal Representation of Seeing an Object

The visual representation of the process of Seeing an Object distributes various percentages. At the Scientific Visualization (SCV) level, the findings showed that ten students (37%) visualized light through arrows from the lamp toward the book and then reflected towards the eyes. At the Simple Visualization (SIV) level, four students (15%) were found who drew arrows from the lamp and from the eyes, each of which pointed to the book. At the Superficial Visualization (SUV) level, one student (4%) made an arrow pointing at a book from a lamp. At the Misconceptions (MIS) level, five students (18%) were found to visualize light through arrows from their eyes pointing toward the book and reflecting towards the lamp. At the Undefined Visualization (UV) level, three students (11%) created a line connecting lamp-book-eye without clear direction. Meanwhile, four students (15%) did not provide any visualization. Several examples of students visually representing seeing an object are presented as in Figure 4.

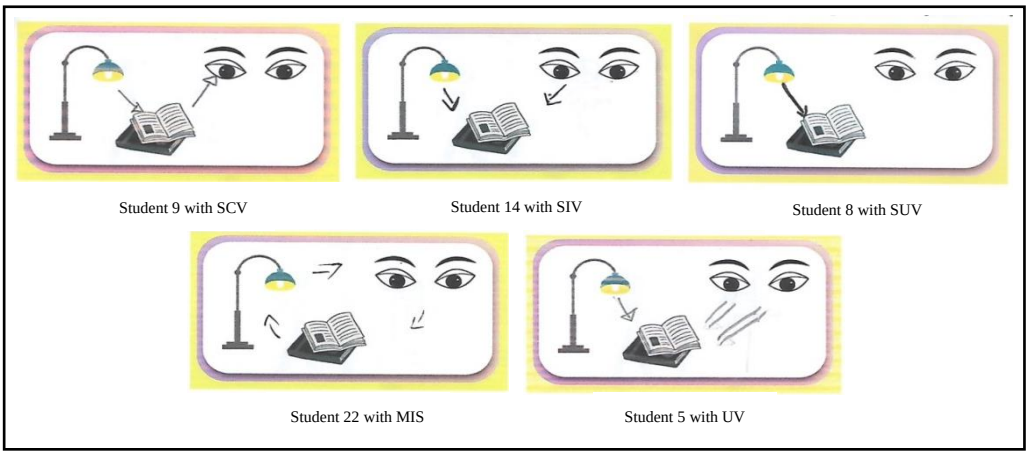

Figure 4. Visual Representation of Seeing an Object

A teacher may have difficulty developing a valid and reliable diagnostic test. Meanwhile, they admit that these prerequisites are needed so that diagnostic tests can accurately provide useful information for student learning progress. Previously, readability tests were carried out on 15 elementary school students and 10 teachers. Most recommendations for improvement from respondents stated that grade 4 students could understand the language used. Internal validity through expert judgment with the content, construct, and language aspects obtained a percentage in the range of 81-100 in all aspects, where this range is included in the Very Valid category as shown in Table 4. External validity is calculated using Corrected Item-Total Correlation with r table 5% and n= 227, so the test results are declared valid if > 0.1303. The results of external validity is presented in Table 5. Meanwhile, reliability is calculated using Cronbach's Alpha and is said to be reliable if the test results are 0.816 (> 0.60). Based on the test results, the development of diagnostic tests that have been carried out can precisely diagnose the representation profile as expected from the objectives of this research.

Table 4. Expert Judgment Validity Results

No.	Rated Aspect	Percentage	Criteria
	Content		
1	The questions and answer choices are formulated clearly according to the sub-topics of the properties of light	93.87	Very Valid
2	Compatibility of question packages with assessment indicators	94.67	Very Valid
3	Clarity of problem context boundaries in the question package	94.13	Very Valid
4	Clarity of the meaning of the verbal questions, level of confidence, and visual questions presented	93.07	Very Valid
5	Compatibility of question sentences with verbal & visual representations	92.80	Very Valid
6	Compatibility of images or similar visualizations to the context of the problem presented in the question	92.53	Very Valid
	Construct		
1	Clarity in the formulation of instructions to do on each question package or each question tier	92.27	Very Valid
2	There are no instructions on the questions to choose the scientific/correct answer	90.40	Very Valid
3	Each question package can identify student misconceptions	90.13	Very Valid
4	The choice of answer reasons (third tier) can reveal the causes of student misconceptions	89.87	Very Valid
5	The choice of answer reasons (third tier) is rational and homogeneous, with the answers at the first tier	90.40	Very Valid
6	The length of the answer choices (first tier) and the reasons for the answers (third tier) are relatively the same	89.60	Very Valid
	Language		
1	The questions use standard Bahasa	91.73	Very Valid
2	The language used is appropriate to the development of elementary school students	93.33	Very Valid
3	The questions do not contain any negative or double statements	93.33	Very Valid
4	Each question package is stated clearly and communicatively	90.93	Very Valid
5	The formulation of the question package does not contain words that could offend students' feelings	95.20	Very Valid
	Average	**92.25**	**Very Valid**

Table 5. Statistical Validity Test Results

Item	Corrected Item-Total Correlation	r_{table} 5%; n: 227	Criteria
Question 1	0.471	0.1303	Valid
Question 2	0.481	0.1303	Valid
Question 3	0.310	0.1303	Valid
Question 4	0.512	0.1303	Valid
Question 5	0.547	0.1303	Valid
Question 6	0.344	0.1303	Valid
Question 7	0.325	0.1303	Valid
Question 8	0.457	0.1303	Valid
Question 9	0.390	0.1303	Valid
Question 10	0.553	0.1303	Valid
Question 11	0.335	0.1303	Valid
Question 12	0.390	0.1303	Valid
Question 13	0.597	0.1303	Valid
Question 14	0.427	0.1303	Valid
Question 15	0.394	0.1303	Valid

Discussion

Based on validity and reliability tests, the development of 5TDT in this research promises useful information for teachers in obtaining information on student representation profiles related to the concept of light. The development of 5TDT that has been carried out can precisely diagnose the representation

profile as expected from the objectives of this research. A valid and reliable diagnostic test will be able to accurately identify students' misconceptions and lack of knowledge and become a reference for teachers in improving the quality of learning in their science classes (Kaltakci-Gurel et al., 2017; Mubarokah, Mulyani, & Indriyanti, 2018). However, teachers may have difficulty developing a valid and reliable diagnostic test. Meanwhile, they admit that these prerequisites are needed so that diagnostic tests can accurately provide useful information for student learning progress. Therefore, researchers developed diagnostic tests with appropriate procedures (Caleon & Subramaniam, 2010; Dewi et al., 2022). If practitioners and academics follow the development procedure step by step, a precise diagnostic test will be created.

Our results about the representation profile diagnosis through 5TDT representation of the light concept show that students dominate the Lack of Representation (LOR) and Misconception (MIS) profiles. This finding aligns with 5TDT research on the heat transfer concept (Anam et al., 2019), where the Lack of Knowledge level dominates at 68% in the conduction concept and 58% in the convection concept, followed by Misconception at 15%. Findings on student representation profiles will illustrate their strengths and weaknesses. Through this diagnostic test, researchers and teachers obtain information on concepts students still need to understand and their way of thinking in answering the test (Banawi et al., 2022). The dominance of a lack of knowledge or representation means that teacher-facilitated learning does not pay attention to students' understanding of related concepts. Teachers have a challenge in reviewing their content and pedagogy because the learning they do does not yet facilitate students' comprehensive understanding of concepts (Syahmel & Jumadi, 2019; Yeo, Yang, & Cho, 2022).

Multiple representations that present concepts in science learning through various forms of representation will have the potential to be more useful because students learn these concepts comprehensively. Hence, students' conceptions lead to more scientific conceptions. Meanwhile, using a single representation in learning is very limited in conveying this information (Asriadi & Istiyono, 2022; Chusni, 2022; Park et al., 2020; Wiyantara et al., 2021). Full support needs to be given to teachers in integrating various representation formats into their learning; this will impact students' mastery of scientific language. Teachers and prospective teachers must experience self-development programs such as training and professional development (Banawi et al., 2022; Wilson & Bradbury, 2021). For example, training in writing multi-mode representation teaching materials using the Triple Step Writing Strategy (TS-WS) can be done because learning content development must overcome problems found during science learning (Handayani, Sinaga, & Suhandi, 2021).

Working on questions and processing 5TDT data takes a long time, which is a limitation of this type of diagnostic test. Therefore, good administration needs to be done, such as separating all items from a concept into several parts. A time lag is needed for researchers and teachers to analyze the data obtained so that the information obtained can be utilized optimally (Caleon & Subramaniam, 2010). However, using diagnostic tests with many levels will provide teachers with a general overview of students' strengths and weaknesses regarding a concept so that teachers can determine appropriate learning. When researchers or teachers want to remediate students, giving pre-learning conceptual change diagnostic tests should not be carried out on the same day because it will not be effective. In addition, elementary school teachers must report diagnostic test results to either the student concerned or the student's parents. This reporting is intended so that parents also support the efforts being made by the teacher (Dewi et al., 2022). Apart from that, the advantages of this type of test are also explained (Anam et al., 2019) that 5TDT can diagnose students' representation profiles in depth, providing a combination of selecting/filling in answers and drawing, as well as providing details of various profile representation categories. After getting useful information from this diagnostic activity, researchers and teachers can design appropriate learning to improve students' representation of light in a more scientific direction—for example, using media or learning models that support multiple representations and conceptual change learning.

These research results have implications for multiple representation learning designs that support conceptual change, add to the administration of diagnostic test question banks on the representation of the concept of light, and provide an analysis of students' learning progression paths in verbal and visual representations. In future, researchers must use or modify diagnostic tests using appropriate development procedures. In addition, these development procedures can also be used as a guideline for developing diagnostic tests and diagnosing cases of representation in other concepts. Furthermore, the results of data analysis from 5TDT can be used in planning remediation programs to increase representation in science learning in elementary schools.

4. CONCLUSION

The 5TDT development that we report meets the validity requirements based on the results of expert judgment and statistical tests, as well as reliability requirements. This prerequisite is necessary to

meet the precision of diagnostic tests for diagnosing students' verbal and visual representations. Through the 5TDT, developed through appropriate procedures, we found that the Lack of Representation (LOR) and Misconception (MIS) profiles dominate students' representations of the concept of light and even its five sub-concepts. Our development description can serve as a guide in developing similar diagnostic tests and how to analyze student work results. In addition, this 5TDT adds to the list bank of diagnostic tests for light representation, and it is possible to continue its development for other scientific concepts in elementary school. Finally, teachers and academics can determine remediation programs through conceptual change learning based on the representation profile found.

5. REFERENCES

Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction*, *16*(3), 183–198. https://doi.org/10.1016/j.learninstruc.2006.03.001.

Akkus, H., Kadayifci, H., & Atasoy, B. (2011). Development and application of a twotier diagnostic test to assess secondary students' understanding of chemical equilibrium concepts. *Journal of Baltic Science Education*, *10*(3), 146–155. https://doi.org/http://oaji.net/articles/2014/987-1410547169.pdf.

Anam, R. S., Widodo, A., Sopandi, W., & Wu, H. K. (2019). Developing a five-tier diagnostic test to identify students' misconceptions in science: an example of the heat transfer concepts. *Elementary Education Online*, *18*(3), 1014–1029. https://doi.org/10.17051/ilkonline.2019.609690.

Asriadi, M., & Istiyono, E. (2022). Multiple representation ability of high school students in physics: a study of modern response theory. *Thabiea: Journal of Natural Science Teaching*, *5*(1), 85–97. https://doi.org/10.21043/thabiea.v5i1.12550.

Aydeniz, M., Bilican, K., & Kirbulut, Z. D. (2017). Exploring pre-service elementary science teachers' conceptual understanding of particulate nature of matter through three-tier diagnostic test. *International Journal of Education in Mathematics, Science and Technology*, *5*(3), 221–221. https://doi.org/10.18404/ijemst.296036.

Banawi, A., Sopandi, W., Kadarohman, A., & Solehuddin, M. (2022). Five-tier multiple-choice diagnostic test development: empirical evidences to improve students' science literacy. *Proceedings of the International Conference on Madrasah Reform 2021 (ICMR 2021)*, *633*(Icmr 2021), 131–138. https://doi.org/10.2991/assehr.k.220104.020.

Cahyanto, M. A. S., Ashadi, A., & Saputro, S. (2019). An analysis of gender difference on students' misconceptions in learning the material classification and its changes. *Jurnal Inovasi Pendidikan IPA*, *5*(2), 157–167. https://doi.org/http://dx.doi.org/10.21831/jipi.v5i2.26613.

Caleon, I. S., & Subramaniam, R. (2010). Do students know What they know and what they don't know? Using a four-tier diagnostic test to assess the nature of students' alternative conceptions. *Research in Science Education*, *40*(3), 313–337. https://doi.org/10.1007/s11165-009-9122-4.

Çelikkanlı, N. Ö., & Kızılcık, H. Ş. (2022). A review of studies about four-tier diagnostic tests in physics education. *Journal of Turkish Science Education*, *19*(4), 1291–1311. https://doi.org/10.36681/tused.2022.175.

Chusni, M. M. (2022). Effectiveness of discovery learning-based multiple representation module on enhancing the critical thinking skills of the students with high and low science process skills. *Jurnal Inovasi Pendidikan IPA*, *8*(2), 199–209. https://doi.org/http://dx.doi.org/10.21831/jipi.v8i2.49340.

Dewi, S. P., Lidyawati, Y., & Destiansari, E. (2022). How is the implementation of diagnostic tests in biology learning in south sumatra? *Jurnal Penelitian Pendidikan IPA*, *8*(6), 2605–2612. https://doi.org/10.29303/jppipa.v8i6.1859.

Dikmenli, M. (2010). Misconceptions of cell division held by student teachers in biology: A drawing analysis. *Scientific Research and Essays*, *5*(2), 235–247. https://doi.org/https://doi.org/10.5897/SRE.9000654.

Dirman, H. M., Mufit, F., & Festiyed, F. (2022). Review and comparison of four-tier multiple choice and five-tier multiple choice diagnostic tests to identify mastery of physics concepts. *Jurnal Penelitian Pendidikan IPA*, *8*(1), 1–12. https://doi.org/10.29303/jppipa.v8i1.838.

Fajriyyah, N., & Ermawati, F. (2020). The validity and reliability of five-tier conception diagnostic test for kinetic theory of gases. *Inovasi Pendidikan Fisika*, *09*(02), 126–132. https://doi.org/https://doi.org/10.26740/ipf.v9n2.p%25p.

Fatimah, S. (2016). Analisis multirepresentasi mahasiswa pgsd pada konsep gelombang dan bunyi. *Premiere Educandum*, *6*(2), 174–179. https://doi.org/http://doi.org/10.25273/pe.v6i02.809.

Halverson, K. L., & Friedrichsen, P. (2013). Learning Tree Thinking: Developing a New Framework of Representational Competence. In D. F. Treagust & C.-Y. Tsui (Eds.), *Multiple Representations in Biological Education*. Dordrecht: Springer.

Handayani, W., Sinaga, P., & Suhandi, A. (2021). Triple step writing strategy: Meningkatkan keterampilan menulis materi ajar multimodus representasi pada mahasiswa calon guru fisika. *Jurnal Inovasi Pendidikan IPA*, *7*(1), 47–60. https://doi.org/http://dx.doi.org/10.21831/jipi.v7i1.37781.

Harfiani, D. R., & Desstya, A. (2023). Mapping science learning in the 2013 curriculum and merdeka belajar curriculum. *Jurnal Ilmiah Sekolah Dasar*, *7*(2), 384–395. https://doi.org/https://doi.org/10.23887/jisd.v7i2.58291.

Hoban, G., Loughran, J., & Nielsen, W. (2011). Slowmation: Preservice elementary teachers representing science knowledge through creating multimodal digital animations. *Journal of Research in Science Teaching*, *48*(9), 985–1009. https://doi.org/10.1002/tea.20436.

Jampel, I. N., Fahrurrozi, Artawan, G., Widiana, I. W., Parmiti, D. P., & Hellman, J. (2018). Studying natural science in elementary school using nos-oriented cooperative learning model with the NHT type. *Jurnal Pendidikan IPA Indonesia*, *7*(2), 138–146. https://doi.org/10.15294/jpii.v7i2.9863.

Juita, Z., Sundari, P. D., Sari, S. Y., & Rahim, F. R. (2023). Identification of physics misconceptions using five-tier diagnostic test: newton's law of gravitation context. *Jurnal Penelitian Pendidikan IPA (JPPIPA)*, *9*(8), 5954–5963. https://doi.org/10.29303/jppipa.v9i8.3147.

Juliani, J., Yusrizal, Y., & Huda, I. (2021). Development of four tier multiple choice diagnostic tests to know students' misconceptions in science learning. *Jurnal Penelitian Pendidikan IPA*, *7*(4), 763–769. https://doi.org/10.29303/jppipa.v7i4.854.

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 and Technological Education*, *35*(2), 238–260. https://doi.org/10.1080/02635143.2017.1310094.

Kartimi, K., Yunita, Y., Fuadi, F. N., & Addiin, I. (2021). A four-tier diagnostic instrument: an analysis of elementary student misconceptions in science topic. *Jurnal Penelitian Pendidikan IPA*, *7*(SpecialIssue), 61–68. https://doi.org/10.29303/jppipa.v7ispecialissue.1022.

Kelana, J. B., Robandi, B., & Widodo, A. (2022). Inquiry model: How to improve the ability of the nature of science and its aspects in elementary school. *International Journal of Elementary Education*, *6*(2), 325–332. Retrieved from https://doi.org/10.23887/ijee.v6i2.45611.

Kokologiannaki, V., & Ravanis, K. (2012). Mental representations of sixth graders in Greece for the mechanism of vision in conditions of day and night. *International Journal of Research In Education Methodology Council for Innovative Research*, *2*(1), 78–83. https://doi.org/10.24297/ijrem.v2i1.4111.

Köse, S. (2008). Diagnosing student misconceptions: Using drawings as a research method. *World Applied Sciences Journal*, *3*(2), 283–293. Retrieved from http://idosi.org/wasj/wasj3(2)/20.pdf.

Lim, H. L., & Poo, Y. P. (2021). Diagnostic test to assess misconceptions on photosynthesis and plant respiration: Is it valid and reliable? *Jurnal Pendidikan IPA Indonesia*, *10*(2), 241–252. https://doi.org/10.15294/jpii.v10i2.26944.

Margunayasa, I. G., Dantes, N., Marhaeni, . A. I. N., & Suastra, I. W. (2021). Reducing misconceptions of elementary school students through guided inquiry learning. *Jurnal Ilmiah Sekolah Dasar*, *5*(4), 729–736. https://doi.org/10.23887/jisd.v5i4.40388.

Masfuah, S., Fakhriyah, F., Wilujeng, I., & Rosana, D. (2021). Diagnostic test profile of scientific literacy to measure student's misconceptions in science concept course. *ELEMENTARY: Islamic Teacher Journal*, *9*(1), 35–56. https://doi.org/10.21043/elementary.v9i1.10382.

Mubarak, S., & Yahdi. (2020). Identifying undergraduate students' misconceptions in understanding acid base materials. *Jurnal Pendidikan IPA Indonesia*, *9*(2), 276–286. https://doi.org/10.15294/jpii.v9i2.23193.

Mubarokah, F. D., Mulyani, S., & Indriyanti, N. Y. (2018). Identifying students' misconceptions of acid-base concepts using a three-tier diagnostic test: A case of Indonesia and Thailand. *Journal of Turkish Science Education*, *15*(Special Issue), 51–58. Retrieved from https://api.elsevier.com/content/abstract/scopus_id/85077227003.

Park, J., Chang, J., Tang, K. S., Treagust, D. F., & Won, M. (2020). Sequential patterns of students' drawing in constructing scientific explanations: focusing on the interplay among three levels of pictorial representation. *International Journal of Science Education*, *42*(5), 677–702. https://doi.org/10.1080/09500693.2020.1724351.

Park, J., Tang, K. S., & Chang, J. (2021). Plan-Draw-Evaluate (PDE) pattern in students' collaborative drawing: Interaction between visual and verbal modes of representation. *Science Education*, *105*(5), 1013–

1045. https://doi.org/10.1002/sce.21668.

Prain, V., & Hand, B. (2016). Learning Science Through Learning to Use Its Languages. In B. Hand, M. McDermott, & V. Prain (Eds.), *Using Multimodal Representations to Support Learning in the Science Classroom*. Switzerland: Springer International Publishing.

Putri, R. A. H., Widodo, A., & Rusyati, L. (2021). Developing a four-tier diagnostic test to identify students' conception on light and optic topic. *Journal of Physics: Conference Series*, *2098*(1), 1–6. https://doi.org/10.1088/1742-6596/2098/1/012008.

Resbiantoro, G., Setiani, R., & Dwikoranto. (2022). A review of misconception in physics: The diagnosis, causes, and remediation. *Journal of Turkish Science Education*, *19*(2), 403–427. https://doi.org/10.36681/tused.2022.128.

Riduwan, & Akdon. (2020). *Rumus dan Data dalam Aplikasi Statistika*. Bandung: Alfabeta.

Schultz, M., Lawrie, G. A., Bailey, C. H., Bedford, S. B., Dargaville, T. R., O'Brien, G., … Wright, A. H. (2017). Evaluation of diagnostic tools that tertiary teachers can apply to profile their students' conceptions. *International Journal of Science Education*, *39*(5), 565–586. https://doi.org/10.1080/09500693.2017.1296980.

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.

Syahmel, S., & Jumadi, J. (2019). Discovery learning using multiple representation model for enhancing scientific processing and critical thinking skills of the students. *Jurnal Inovasi Pendidikan IPA*, *5*(2), 180–194. https://doi.org/10.21831/jipi.v5i2.26704.

Tang, K. S., Delgado, C., & Moje, E. B. (2014). An integrative framework for the analysis of multiple and multimodal representations for meaning-making in science education. *Science Education*, *98*(2), 305–326. https://doi.org/10.1002/sce.21099.

Uzun, S., Alev, N., & Karal, I. S. (2013). A cross-age study of an understanding of light and sight concepts in physics. *Science Education International*, *24*(2), 129–149. Retrieved from https://files.eric.ed.gov/fulltext/EJ1015829.pdf.

Widiyatmoko, A., & Shimizu, K. (2018). The development of two-tier multiple choice test to assess students' conceptual understanding about light and optical instruments. *Jurnal Pendidikan IPA Indonesia*, *7*(4), 491–501. https://doi.org/10.15294/jpii.v7i4.16591.

Wilson, R. E., & Bradbury, L. U. (2021). Assessing early primary students' growth in a science unit using multiple modes of representation: investigating the promise of explicit drawing instruction. *International Journal of Science Education*, *43*(8), 1341–1364. https://doi.org/10.1080/09500693.2021.1909774.

Wiyantara, A., Widodo, A., & Prima, E. C. (2021). Identify students' conception and level of representations using five-tier test on wave concepts. *Journal of Physics: Conference Series*, *1806*(1), 1–7. https://doi.org/10.1088/1742-6596/1806/1/012137.

Xu, L., Prain, V., & Speldewinde, C. (2021). Challenges in designing and assessing student interdisciplinary learning of optics using a representation construction approach. *International Journal of Science Education*, *43*(6), 844–867. https://doi.org/10.1080/09500693.2021.1889070.

Yeo, J.-H., Yang, H.-H., & Cho, I.-H. (2022). Using a three-tier multiple-choice diagnostic instrument toward alternative conceptions among lower-secondary school students in taiwan: Taking ecosystems unit as an example. *Journal of Baltic Science Education*, *21*(1), 69–83. https://doi.org/10.33225/jbse/22.21.69.