Volume 13. Issue 1. 57-67 JUNE 2024

Jurnal Ilmiah Pendidikan Fisika Al-BiRuNi
https://ejournal.radenintan.ac.id/index.php/al-biruni/index
DOI: 10.24042/jipfalbiruni.v13i1.17155

P-ISSN: 2303-1832
e-ISSN: 2503-023X

How to Develop Visual Representation Test Instruments on Optical Equipment Material for High School Students?

Utari Nurmahasih[1*], Edi Istiyono[2], Deni Sadly[3], Warjo[4]

[1, 2] Physical Education, Yogyakarta State University, Yogyakarta, Indonesia
[3] Physical Education, Sriwijaya University, Palembang, Indonesia
[4] Physical Education Teacher, Madrasah Aliyah Negeri 1 Yogyakarta, Yogyakarta, Indonesia

Corresponding Address: utarinurmahasih.2022@student.uny.ac.id

Article Info

Article history:

Received: July 04, 2023
Accepted: April 23, 2024
Published: June 29, 2024

Keywords:

Evaluation instrument;
Optical tools;
Research and development (R&D);
Representative visual.

ABSTRACT

In physics learning, visual representation is an important tool for turning abstract concepts into more easily understood ones, especially topics about optical equipment. However, current teaching instruments are often less effective in providing adequate visualization. This research on the development of visual representation test instruments for senior high school or Islamic senior high school (SMA/MA) on optical device topic was carried out with the aims of 1) developing a visual representation test instrument on optical devices material, 2) determining the expert validity of the visual representation instrument on optical devices material, 3) determine the item validity and reliability of the visual representation instrument on optical devices material through limited trials, 4) determine the level of difficulty and differentiability of visual representation instruments on optical devices material. This research design was the Research and Development (R&D) procedure from Borg and Gall, which was modified up to the product trial stage. Data was collected from the expert validation and product trials and then analyzed using a quantitative description. Eight validators validated the visual representation instrument. The research subjects were 30 eleventh-grade science students. The results of the analysis concluded that the product was suitable for use by teachers in assessing student representation. Therefore, the visual representation test instrument for optical devices material is suitable for teachers. Through this instrument, it is hoped that we can see the ability of students' representation instruments in learning optics.

INTRODUCTION

Technological developments in this modern era have brought significant changes in various aspects of life, including in education (Chu et al., 2023, and Salsabila et al., 2021). Information and communication technology is integral to learning (Peng et al., 2023). ICT facilitates access to extensive information and knowledge (Lo, 2023). It also provides a platform for effective interaction and collaboration (Zhang et al., 2023; Guan et al., 2023). In this case, technology has changed how we understand and apply scientific concepts, including physics. In physics, technology has made it possible to use computer simulations to visualize and understand complex concepts, such as quantum mechanics or relativity.

Studying physics is often a challenge for many students because concepts in physics are usually abstract and complex (Kwarikunda et al., 2022). Without strong foundational knowledge or visual aids, these concepts can be difficult to understand (Poldrack, 2021). For example, students' conceptual understanding of geometric

How to cite Nurmahasih, U., Istiyono, E., Sadly, D., & Warjo, W. (2024). How to develop visual representation test instruments on optical equipment material for high school students?. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni, 13*(1), 57-67.

optics material is still in the low category, namely 53.44 (Wahyuni & Taqwa, 2022). 55% of students experience misconceptions about optical instruments (Purwaningtias & Putra, 2020). However, students can more easily understand physics concepts through a visual learning approach. For example, the laws of reflection and refraction of light in optics can become clearer to students with the help of visualization. Without visualization, students may have difficulty imagining how light interacts with various media and changes direction. However, with the help of optical simulation applications, students can 'see' how light is reflected or refracted when it passes through media with different refractive indices, such as water or glass.

The topic of optical instruments is one of the topics in the high school physics curriculum, which often causes difficulties for students. This material involves concepts such as light refraction, optical lenses (Fliegauf et al., 2022), flat and curved mirrors, and their applications in everyday life (Uwamahoro et al., 2021). Students' misunderstandings in learning optical instruments occur in the concepts of the eye, camera, magnifying glass (Wahyuni & Taqwa, 2022), microscope, and telescope (Widiyatmoko & Shimizu, 2019). Misunderstandings also occur in understanding the complex concepts of light and optical instruments (Kaniawati et al., 2020). To help students understand these concepts better, learning evaluations are needed that can improve and measure students' understanding.

Students' understanding of optical learning can be improved through visual representations. Visual representations help students visualize abstract (Zheng et al., 2022) and complicated concepts in optics (Sunarti & Amiruddin, 2022), such as reflection and refraction of light (Widiyatmoko & Shimizu, 2019), into images or diagrams that are easier to understand (Sebald et al., 2022). Besides, this visual aid can also increase student involvement in the teaching (He et al., 2022) and learning process (Aoudni et al., 2023) and encourage creative problem-solving (Fliegauf et al., 2022). Thus, optical learning becomes more effective and interactive with visual representations.

Representations can be physical objects, pictures, diagrams, graphs, and symbols, making it easier for students to communicate their thoughts (Saputra et al., 2019; Putri et al., 2020). According to Inayah (2018), there are several types of representation: symbolic, visual, and verbal. In this context, assessment instruments involving visual representations are essential in measuring students' understanding of the material.

The development of visual representation instruments in optical instruments for senior high school is very high. Several causing factors: first, the topic of optical instruments is a topic in physics that has a high level of complexity (Wei et al., 2022) and requires a deep conceptual understanding (Prahani et al., 2021). Students may struggle to understand (Kang, 2021) and apply these concepts in natural contexts (Spicer & Coleman, 2022). Second, traditional learning methods are often ineffective in helping students understand abstract concepts like these (Migdał et al., 2022). Visual representation instruments can make learning more interactive (Chonavel, 2000) and interesting for students (Areljung et al., 2022). It can help them understand the material more efficiently and increase their involvement in the learning process. Third, increasing students' understanding of optical instruments is also essential to stimulate their interest in further physics studies (Taqwa & Rahim, 2022). With a good understanding of this topic, students will likely feel more interested in exploring other areas of physics.

Previous research has provided important insights into the field of optical learning. Students' understanding of physics concepts showed an average score of 53.44 with 26.2% of students not understanding at all according to (Wahyuni & Taqwa, 2022). Widiyatmoko & Shimizu (2018) found that teacher language and textbooks that are difficult to understand are the main causes of misconceptions, while Purwaningtias & Putra (2020) and Wei et al. (2022) showed that the highest misconceptions occurred like mirrors and convex lenses with a percentage of 61%. According to Sartika et al. (2021), misconceptions can be demonstrated through visual representations, such as images of the base and height of a triangle. Afriani et al. (2013) showed that using cross-linguistic visual representations effectively overcame learning barriers. Furthermore, Nurulhasni et al. (2023) found that the critical thinking instruments and visual representations developed were valid and reliable and fit the Rasch model.

In this article, we will discuss the development of a visual representation assessment instrument that is relevant and effective in learning optical instruments for senior high school students. The difference between this research and the previous one lies in its focus on developing visual representation test instruments for optical equipment materials. The novelty of this research is the application of visual representation in the test instrument and determining the level of difficulty and discriminating index of the instrument. The objectives of this article are: 1) to develop a visual representation test instrument on the subject of senior high school or Islamic senior high school optical devices, 2) to determine the expert validity of the visual representation instrument on optical devices material, 3) to determine the item validity and reliability of the visual representation instrument on optical devices material through limited trials, 4) knowing the level of difficulty and discriminating power of visual representation instruments on optical devices material.

METHODS

This research employs a quantitative approach with a Research and Development (R&D) design or model. The Borg & Bile (2003) method was used as the model. The steps are (1) research and information gathering, (2) planning, (3) development of primary product form, (4) field introduction, (5) revision of primary product, (6) main field test, (7) operational revision product (8) operational field testing, (9) final product revision, and (10) socialization and implementation. This research was only carried out until stage 6 (limited trials) because this research aimed to see the results of product trials. The procedure for developing visual representation instruments carried out by researchers can be seen in Figure 1.

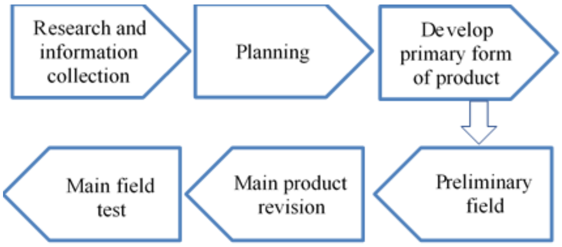


Figure 1. Instrument Development Procedures

The final stage was validation by eight physics teaching practitioners. The test instrument was then tested on 40 high school students. The data was collected through questionnaires for assessing the quality of test instruments based on the expert validators. The questionnaire will obtain an expert's product quality validation regarding material, construct, and language. Expert validity analysis uses Aiken's V equation.

$$V = \frac{\sum s}{[n(c-1)]} \quad (1)\text{(Aiken, 1985)}$$

Then

s = r- lo

Description:
V= Index of expert agreement on item content
s= The score assigned by the expert minus the lowest score in the category used
r= Score given by expert
l_0= The lowest score in the rating category
n= Number of experts
c= The number of categories selected by experts

An instrument is considered valid if its value is equal to or higher than 0,92. To obtain valid instruments, invalid instruments will be corrected according to the suggestions of validators. In addition, the instruments developed were also tested for empirical validity.

Empirical validity is used to validate each item. It was carried out in the eleventh-grade Natural Science and Mathematics classes. Validity aims to determine valid items and can be used to measure visual representation aspects. Empirical validity was analyzed with SPSS software, while Cronbach Alpha analysis was used for the reliability test.

Based on empirical test data, the validity and reliability of the items are followed by determining their discriminating power and difficulty level. Trials of discriminating power and difficulty level of the test items were carried out using the Excel program.

RESULTS AND DISCUSSION

1. Research and Information Collection

The analysis results from the literature study showed that students were less interested in learning physics. Another obstacle also arises when the teacher knows very little about visual representations. Therefore, the teacher needs to learn the visual representations. Because there is no assessment of visual representations, teachers still need to understand how to measure visual representation competencies in physics learning. The success of achieving students' visual representation will be determined mainly by the teacher's ability to develop and use the constructed measuring instrument correctly and analyze the information generated by the measuring instrument.

2. Planning

The next step was preparing the instrument specification. The evaluation instrument developed in this research is the visual representation test instrument. The developed visual representation test instrument refers to visual representation indicator questions on the product. The specification of the visual representation test instrument can be seen in Table 1.

Table 1. Instrument Specification of Visual Representation Test in the Aspect of Explaining Optical Instruments Material

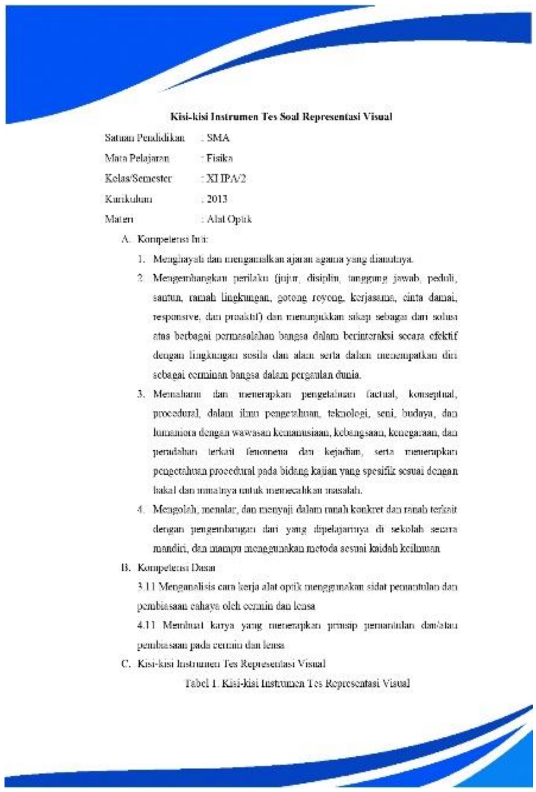
No	Visual Representation Indicators	Question Indicator	Cognitive Dimension	Question Number
1.	Presenting data or information to represent pictures, diagrams, or tables	Present a picture of an eye: Students can select the right part of the eye based on the function mentioned.	C4	2
		Present a statement regarding myopia eye disorders: Students can sort the correct picture based on this statement.	C4	4
		Present remote point data for people with eye disabilities: Students can diagnose the strength of glasses that people with eye disabilities should use.	C4	6
		Present a statement of the condition of observing an object through rotation with maximum eye accommodation: Students can conclude the correct image-forming image.	C5	12
		Present observational data of an object through a microscope: Students can organize the correct image based on that data.	C4	33
2.	Use pictures to clarify problems and facilitate their resolution	Present an image of the formation of the image of an object through the image on the microscope: Students can formulate the length of the microscope	C4	32
		Present angular magnification data on observations using a loop: Students can determine the right image to obtain magnification at that value.	C3	15

No	Visual Representation Indicators	Question Indicator	Cognitive Dimension	Question Number
		Present a picture of a camera and the function of its parts: Students can sort the correct parts based on these functions.	C4	24
		Present a magnified image of a loop used to observe when the eye is not accommodated to the maximum: Students can formulate the focus of the loop.	C4	21
		Present an image of image formation through a loop: Students can determine the angular magnification resulting from the image.	C3	17

3. Develop a Primary Form of Product

After the specification, the next step was preparing a visual representation item. The visual representation test instrument in the initial draft consisted of 10 items prepared for development.

Figure 2. The Cover of Visual Representation Instrument



Kisi-kisi Instrumen Tes Soal Representasi Visual

Satuan Pendidikan : SMA
Mata Pelajaran : Fisika
Kelas/Semester : XI IPA/2
Kurikulum : 2013
Materi : Alat Optik

A. Kompetensi Inti:
1. Menghayati dan mengamalkan ajaran agama yang dianutnya.
2. Mengembangkan perilaku (jujur, disiplin, tanggung jawab, peduli, santun, ramah lingkungan, gotong royong, kerjasama, cinta damai, responsive, dan proaktif) dan menunjukkan sikap sebagai dari solusi atas berbagai permasalahan bangsa dalam berinteraksi secara efektif dengan lingkungan sosila dan alam serta dalam menempatkan diri sebagai cerminan bangsa dalam pergaulan dunia.
3. Memahami dan menerapkan pengetahuan factual, konseptual, procedural, dalam ilmu pengetahuan, teknologi, seni, budaya, dan humaniora dengan wawasan kemanusiaan, kebangsaan, kenegaraan, dan peradaban terkait fenomena dan kejadian, serta menerapkan pengetahuan procedural pada bidang kajian yang spesifik sesuai dengan bakat dan minatnya untuk memecahkan masalah.
4. Mengolah, menalar, dan menyaji dalam ranah konkret dan ranah terkait dengan pengembangan dari yang dipelajarinya di sekolah secara mandiri, dan mampu menggunakan metoda sesuai kaidah keilmuan

B. Kompetensi Dasar

3.11 Menganalisis cara kerja alat optik menggunakan sifat pemantulan dan pembiasaan cahaya oleh cermin dan lensa

4.11 Membuat karya yang menerapkan prinsip pemantulan dan/atau pembiasaan pada cermin dan lensa

C. Kisi-kisi Instrumen Tes Representasi Visual

Tabel 1. Kisi-kisi Instrumen Tes Representasi Visual

Figure 3. Visual Representation Instrument

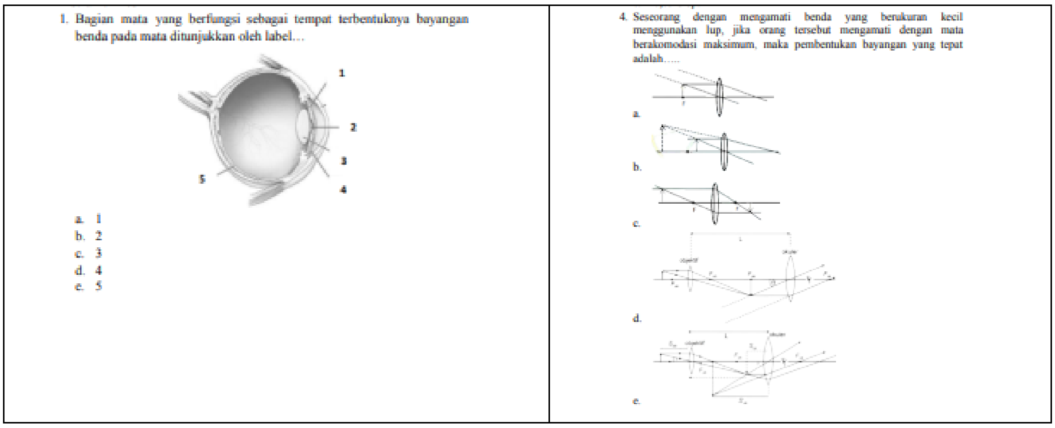


Figure 4. Visual Representation Instrument Sheet

The question instrument developed is designed to hone students' understanding of visual representations. Question number 1 asks students to understand the visualization of the image of the eye. In contrast, question number 2 requires an understanding of visualizing the image's shape in the eye. Question number 3 requires understanding from visual and verbal to mathematical form. Questions 4 and 5 focus on understanding image visualization, while numbers 6 and 7 require understanding the visual representation of loupe image formation. Question number 8 focuses on understanding the visual representation of camera parts, number 9 on the visual representation of microscope magnification, and number 10 asks for an understanding of the transition from mathematical representation to visual representation.

4. Preliminary Field Trial

The next step is the expert validation stage after the visual representation test instrument has been made. The results of the expert validation were analyzed using Aiken's V index. Table 2 shows the results of the expert validation.

Table 2. Overall Validity Results of Test Items

Question Items	Aiken V Index	Category
1	0,92	High Validity
2	0,92	High Validity
3	1	High Validity
4	1	High Validity
5	0,83	High Validity
6	1	High Validity
7	0,92	High Validity
8	1	High Validity
9	1	High Validity
10	1	High Validity
Overall Validity	0,96	Valid

Table 2 shows that Aiken's overall V score was 0.96. The visual representation test instrument developed belonged to the valid category.

5. Main Product Revision

After the experts had validated the visual representation test instrument, revisions were made according to the validators' suggestions. This stage was carried out to improve the product before the testing. Some of the main things that became input from the four assessors included (1) the procedure for writing was not quite right, for example, combining or separating sentences, and (2) the sentences on the instrument should go straight to the root of the problem.

6. Main Field Test

The revised product was tested in a limited trial. A limited trial was conducted on 40 eleventh-grade natural science and mathematics students.

Quality Analysis of Test Sets

A Microsoft Office Excel program for data tabulation assisted the analysis. The resulting analysis of the questions included validity, reliability, level of difficulty, and differentiating power of the questions. From the calculation of the field trial, the validity of the questions obtained is as follows:

Table 3. The Results of the Validity Test

Question Items	$r_{critical}$	$r_{observed}$	Criteria
Item 1	0,312	0,486	Valid
Item 2		0,479	Valid
Item 3		0,569	Valid
Item 4		0,549	Valid
Item 5		0,607	Valid
Item 6		0,586	Valid
Item 7		0,128	Invalid
Item 8		0,313	Valid
Item 9		0,633	Valid
Item 10		0,541	Valid

From the empirical test data analysis results, as shown in Table 3 above, the value for item numbers 1, 2, 3, 4, 5, 6, 8, 9, and 10 is more significant than $r_{critical}$; thus, the items were declared valid. However, item 7 is smaller than $r_{critical}$ or invalid. Therefore, item number 7 needs to be corrected.

In addition, a reliability analysis test using Cronbach's Alpha was also carried out, as Table 4 shows.

Table 4. The Results of the Reliability Analysis

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0,715	0,758	9

From Table 4, the Cronbach's alpha value is 0.715, higher than 0.70. Therefore, the test instrument was reliable.

The difficulty analysis of the instrument obtained the following results:

Table 5. The Analysis of the Difficulty Level of the Questions

No	Category	Question Number	Total	Percentage
1	Easy	3,4,7,8	4	40%
2	Moderate	1,2,6,9,10	5	50%
3	Hard	5	1	10%
	Total		10	100%

The difficulty level analysis found four items (40%) in the easy category, five in the moderate category with a percentage of 50%, and one in the hard category with a percentage of 10%.

The discriminating power analysis obtained the following results:

Table 6. The Analysis of the Discriminating Power

No	Category	Question number	Total	Percentage
1	Excellent	9	7	70%
2	Good	1,2,3,4,5,6,10	1	10%
3	Poor	7,8	2	20%
	Total		10	100%

The data conclude that the instrument's validity is excellent, as evidenced by the empirical trial analysis with nine valid items. The 7th item is declared invalid, so it needs to be revised. The items are declared reliable on the reliability test. Then, from the analysis results, the difficulty level of the items made by the researcher was proportional because, overall, more questions were classified as moderate, difficult, and easy. Moreover, the test instrument has good discriminatory power.

This research produced a visual representation test instrument for optical device material in senior high school or Islamic senior high school. This instrument has been validated by experts with an Aiken V score of 0.96, which is included in the valid category. It has also been tested empirically on eleventh-grade students. Besides, this test instrument's level of difficulty and discriminating power are also considered good.

Compared with previous research by Nurulhasni et al. (2023), this research has a more specific focus, namely on developing test instruments with visual representations of optical instrument material. This focus is interesting because, through this approach, students are expected to understand the material by visualizing the studied concepts. Also, the results of this research show that the test instrument is valid and reliable, which means this instrument can be used to accurately measure students' understanding of optical devices.

CONCLUSION AND SUGGESTION

Based on the discussion and development results, a visual representation instrument has been produced for the material of senior high school or Islamic senior high school optical devices. Therefore, the conclusions of this research are 1) the developed test instrument on the optical devices material includes visual representation aspects, 2) the visual representation test instrument on optical devices material has been validated by experts, with an overall Aiken's V score of 0.96, included in the valid category, and 3) the visual representation test instrument on optical devices has been tested empirically on the eleventh-grade students. The empirical trial analysis found that nine items were declared valid and reliable. Also, through the test results, the level of difficulty and the discriminating power of the test instruments was stated to be good.

Further research is suggested to conduct broader trials. Although it has been tested on eleventh-grade students, this research could be expanded by conducting trials on students in other classes or at other schools. This will help further validate the test instrument and ensure that it is effective for various groups of students.

ACKNOWLEDGMENT

Thank you to physics teacher practitioners and students of MAN 1 Yogyakarta who have helped carry out this research.

AUTHOR CONTRIBUTION

UN contributed to designing and carrying out the research, collecting data, conducting statistical analysis, and preparing the initial manuscript draft. UN also participated in creating visual representation instruments and assisted in data collection. EI participated in guiding the writing of the article, providing critical supervision of the content of the article, and providing suggestions regarding the ideas generated. DS had a crucial role in designing the study and interpreting the results of the data analysis. He also assisted in reviewing and revising manuscript drafts for important intellectual content. W facilitated access to the schools where the research was conducted and contributed to interpreting the results.

REFERENCES

Afriani, D., Rifaat, M., & Hamdani. (2013). Pengembangan representasi visual dalam lintasan kebahasaan pada teorema pythagoras. *Jurnal UNTAN*.

Aiken, L. R. (1985). Three coefficients for analyzing the reliability and validity of ratings. *Educational and Psychological Measurement*, *45*(1), 131–142.

Aoudni, Y., Kalra, A., Azhagumurugan, R., Ahmed, M. A., Wanjari, A. K., Singh, B., & Bhardwaj, A. (2023). Correction to: Metaheuristics based tuning of robust pid controllers for controlling voltage and current on photonics and optic. *Optical and Quantum Electronics*, *55*(6), 11082. https://doi.org/10.1007/s11082-023-04794-w

Areljung, S., Skoog, M., & Sundberg, B. (2022). Teaching for emergent disciplinary drawing in science? comparing teachers' and children's ways of representing science content in early childhood classrooms. *Research in Science Education*, *52*(3), 909–926. https://doi.org/10.1007/s11165-021-10036-4

Chonavel, T. (2000). A deep learning

powered system to lie detection while online study. *Traitement Du Signal*, *39*(3), 893–898. https://doi.org/https://doi.org/10.18280/ts.390314

Chu, J., Lin, R., Qin, Z., Chen, R., Lou, L., & Yang, J. (2023). Exploring factors influencing pre-service teacher's digital teaching competence and the mediating effects of data literacy: Empirical evidence from China. *Humanities and Social Sciences Communications*, *10*(1), 1–11. https://doi.org/10.1057/s41599-023-02016-y

Fliegauf, K., Sebald, J., Veith, J. M., Spiecker, H., & Bitzenbauer, P. (2022). Improving early optics instruction using a phenomenological approach: A field study. *Optics*, *3*(4), 409–429. https://doi.org/10.3390/opt3040035

Guan, X., Feng, X., & Islam, A. Y. M. A. (2023). The dilemma and countermeasures of educational data ethics in the age of intelligence. *Humanities and Social Sciences Communications*, *10*(1). https://doi.org/10.1057/s41599-023-01633-x

He, X., Singh, C. K. S., & Ebrahim, N. A. (2022). Quantitative and qualitative analysis of higher-order thinking skills in blended learning. *Perspektivy Nauki i Obrazovania*, *59*(5), 397–414. https://doi.org/10.32744/pse.2022.5.23

Wahyuni , I.H., & Taqwa, M.R.A. (2022). Level of students conceptual understanding and resource theory view: Geometric optics. *International Journal of Education and Teaching Zone*, *1*(2), 146–158. https://doi.org/10.57092/ijetz.v1i2.38

Inayah, S. (2018). Peningkatan kemampuan pemecahan masalah dan representasi multipel matematis dengan menggunakan model pembelajaran kuantum. *KALAMATIKA Jurnal Pendidikan Matematika*, *3*(1), 1–16. https://doi.org/10.22236/kalamatika.vol3no1.2018pp1-16

Kang, K. (2021). Characteristics of an Infographic Presented in Physics i Textbooks according to the 2015 Revised Curriculum - In focus on "Waves and Info-communication." *New Physics: Sae Mulli*, *71*(11), 921–928. https://doi.org/10.3938/NPSM.71.921

Kaniawati, I., Rahmadani, S., Fratiwi, N. J., Suyana, I., Danawan, A., Samsudin, A., & Suhendi, E. (2020). An analysis of students' misconceptions about the implementation of active learning of optics and photonics approach assisted by computer simulation. *International Journal of Emerging Technologies in Learning*, *15*(9), 76–93. https://doi.org/10.3991/ijet.v15i09.12217

Kwarikunda, D., Schiefele, U., Muwonge, C. M., & Ssenyonga, J. (2022). Profiles of learners based on their cognitive and metacognitive learning strategy use: occurrence and relations with gender, intrinsic motivation, and perceived autonomy support. *Humanities and Social Sciences Communications*, *9*(1), 1–12. https://doi.org/10.1057/s41599-022-01322-1

Lo, N. P. kan. (2023). Digital learning and the esl online classroom in higher education: teachers' perspectives. *Asian-Pacific Journal of Second and Foreign Language Education*, *8*(1), 1–22. https://doi.org/10.1186/s40862-023-00198-1

Migdał, P., Jankiewicz, K., Grabarz, P., Decaroli, C., & Cochin, P. (2022). Visualizing quantum mechanics in an interactive simulation – virtual lab by quantum flytrap. *Optical Engineering*, *61*(08), 1–26. https://doi.org/10.1117/1.oe.61.8.081808

Nurulhasni, D., Nurbaiti, E. A., & Nabila, R. S. (2023). Developing and implementing an instrument for assessing critical thinking and visual representations in learning physics materials of optical instruments. *Jurnal Penelitian dan Evaluasi Pendidikan*, *27*(1), 52–62. https://doi.org/http://journal.uny.ac.id/index.php/jpep Developing

Peng, R., Razak, R. A., & Halili, S. H. (2023). Investigating the Factors affecting ICT Integration of in-service teachers in Henan Province, China: Structural equation modeling. *Humanities and Social Sciences Communications*, *10*(1), 1–11. https://doi.org/10.1057/s41599-023-01871-z

Poldrack, R. A. (2021). The physics of representation. *Synthese*, *199*(1–2), 1307–1325. https://doi.org/10.1007/s11229-020-02793-y

Prahani, B. K., Deta, U. A., Lestari, N. A., Yantidewi, M., Rjauhariyah, M. N., Kelelufna, V. P., Siswanto, J., Misbah, M., Mahtari, S., & Suyidno, S. (2021). A profile of physics multiple representation ability of senior high school students on heat material. *Journal of Physics: Conference Series*, *1760*(1). https://doi.org/10.1088/1742-6596/1760/1/012020

Purwaningtias, W. S., & Putra, N. M. D. (2020). Analisis tingkat pemahaman konsep dan miskonsepsi fisika pada pokok bahasan alat-alat optik di SMA Negeri 1 Purwodadi. *UPEJ Unnes Physics Education Journal*, *9*(2), 139–148. https://journal.unnes.ac.id/sju/index.php/upej/article/view/41920

Putri, H. N. P. A., Wulandari, R. N., Fitriana, A., & Kusairi, S. (2020). The comparison of high school students' understanding of kinematic materials: Case of question representations. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *9*(2), 241–249. https://doi.org/10.24042/jipfalbiruni.v9i2.6032

Salsabila, U. H., Ilmi, M. U., Aisyah, S., Nurfadila, N., & Saputra, R. (2021). Peran teknologi pendidikan dalam meningkatkan kualitas pendidikan di era disrupsi. *Journal on Education*, *3*(01), 104–112. https://doi.org/10.31004/joe.v3i01.348

Saputra, A. T., Jumadi, J., Paramitha, D. W., & Sarah, S. (2019). Problem-solving approach in multiple representations of qualitative and quantitative problems in kinematics motion. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *8*(1), 89–98. https://doi.org/10.24042/jipfalbiruni.v8i1.3801

Sartika, I., Rifat, M., & T, A. Y. (2021). Pengembangan instrumen tes untuk mengungkap sumber miskonsepsi berdasarkan representasi visual dalam segitiga. *Jurnal Pendidikan dan Pembelajaran Khatulistiwa (JPPK)*, *10*(1), 1–10. https://doi.org/10.26418/jppk.v10i1.44087

Sebald, J., Fliegauf, K., Veith, J. M., Spiecker, H., & Bitzenbauer, P. (2022). The world through my eyes: Fostering students' understanding of basic optics concepts related to vision and image formation. *Physics (Switzerland)*, *4*(4), 1117–1134. https://doi.org/10.3390/physics4040073

Spicer, J. O., & Coleman, C. G. (2022). Creating effective infographics and visual abstracts to disseminate research and facilitate medical education on social media. *Clinical Infectious Diseases*, *74*(Suppl 3), E14–E22. https://doi.org/10.1093/cid/ciac058

Sunarti, T., & Amiruddin, M. Z. B. (2022). Analysis multi representation ability and learning outcomes of optical materials. *Journal of Physics: Conference Series*, *2392*(1). https://doi.org/10.1088/1742-6596/2392/1/012009

Taqwa, M. R. A., & Rahim, H. F. (2022). Students' Conceptual understanding on vector topic in visual and mathematical representation: A comparative study.

Journal of Physics: Conference Series, *2309*(1). https://doi.org/10.1088/1742-6596/2309/1/012060

Uwamahoro, J., Ndihokubwayo, K., Ralph, M., & Ndayambaje, I. (2021). Physics students' conceptual understanding of geometric optics: revisited analysis. *Journal of Science Education and Technology*, *30*(5), 706–718. https://doi.org/10.1007/s10956-021-09913-4

Wei, B., Wang, C., & Tan, L. (2022). Visual representation of optical content in China's and Singapore's junior secondary physics textbooks. *Physical Review Physics Education Research*, *18*(2), 20138. https://doi.org/10.1103/PhysRevPhysEducRes.18.020138

Widiyatmoko, A., & Shimizu, K. (2019). Development of computer simulations to overcome students misconceptions on light and optical instruments. *Journal of Physics: Conference Series*, *1321*(3). https://doi.org/10.1088/1742-6596/1321/3/032074

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

Zhang, Y., Chen, X., & Shen, Z. (2023). Internet use, market transformation, and individual tolerance: Evidence from China. *Humanities and Social Sciences Communications*, *10*(1), 1–12. https://doi.org/10.1057/s41599-023-01781-0

Zheng, R., Cordner, H., & Spears, J. (2022). The impact of annotation on concrete and abstract visual representations in science education: Testing the expertise reversal effect. *Research and Practice in Technology Enhanced Learning*, *17*(1). https://doi.org/10.1186/s41039-022-00194-y