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# Development of an augmented reality integrated Problem-Solving Laboratory Model (PSLab-AR) for electricity concepts to enhance the students' understanding of concepts

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**Abstract**: This research aims to develop a product in the form of an integrated Augmented Reality Problem Solving Laboratory (PSLab-AR) model. The research method used in this research is research and development because it is in line with the main output of this research. The research design used consists of the Define, Design, Develop and Disseminate stages. Participants in this research consisted of three groups: the first group was two elementary school teachers at the define stage, three science education experts at the development stage, and 25 fifth grade students at the dissemination stage. This research uses a CVI validation sheet and 10 questions on students' conceptual understanding. Based on the needs analysis at the definition stage, PSLab-AR is needed to assist science learning in elementary schools, especially in providing an interesting representation of the abstract concept of electricity. During the Design and Development stage, we found that the PSLab-AR framework passed expert evaluation by producing a framework consisting of preparation stages (understanding the practicum objectives, reading materials, and answering questions), problem solving (studying the problem context, formulating the problem, and creating prediction), exploration (determining tools and materials, understanding tool function, and creating procedures), measurement, data analysis, and drawing conclusions. At the dissemination stage, the research results showed that the Augmented Reality Integrated Problem Solving Laboratory model could increase students' conceptual understanding by 27.6 with an N-gain value of 0.610 in the medium category.
**Keywords**: problem solving laboratory; augmented reality; electricity concepts

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## Introduction

Indonesia currently still faces several complex problems in the field of science. Organization for Economic Cooperation and Development (OECD) research results through the Programme for International Student Assessment (PISA) test placed Indonesia at rank 67 out of 81 countries (OECD, 2023), which in this position, performance of Indonesian students in science was under average of all countries . This poses a challenge for all authorities in the field of education to continue innovating and improving their skills in an effort to enhance the quality of education in Indonesia, especially in science education.


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Efforts that can be made to address these issues include innovating in science laboratory practices. Currently, there are two forms of laboratory methods commonly used in learning, namely real and virtual laboratories. Real and virtual laboratories both have their own advantages and disadvantages. Therefore, comparing real and virtual laboratories is unnecessary. However, finding the right strategy to combine the two experiments is invaluable (Holmes & Lewandowski, 2020; Taghavi & Jr, 2009; Zacharia & Olympiou, 2011). One way to integrate both laboratories at the same time is by incorporating Augmented Reality (AR) technology.

In physics labs, the development of AR technology is yet hardly ever utilized (Ismail, Setiawan, et al., 2019). As of right now, AR technology is only being used in instructional media in a few nations, including Mexico, China, and Turkey (Chang & Hwang, 2018; Fidan & Tuncel, 2019; Ibáñez et al., 2020). In Indonesia, where it hasn't been immediately incorporated into laboratory procedures, a comparable circumstance exists (Ismail, 2021; Ismail, Festiana, et al., 2019). However, laboratory practices, which serve as the main source of learning for students, can be better optimized by integrating AR technology as a technology-based modality. The importance of integrating AR into laboratory practices is based on several reasons. Firstly, AR provides a different experience for students by immersing them in an environment that combines the real and virtual worlds (Ibáñez et al., 2020). Secondly, it adds multimodality in representing concepts (Wu et al., 2013). Through the integration of AR, modalities in the form of interactive phenomena can be accessed directly by students in the laboratory with the help of technology. For example, students can access the motion of electrons in an electrical circuit when modalities in the form of AR are provided in the laboratory. Third, dynamic visualisation while learning with AR technology improves students' understanding levels in grasping abstract concepts (Ismail, Festiana, et al., 2019).

Understanding scientific concepts alone is not sufficient to address the challenges of the 21st century. This is because, in addition to understanding concepts, students are required to be able to solve problems (Balta & Asikainen, 2019; Nita et al., 2023). One suitable laboratory model (Huang et al., 2020; Price et al., 2022) to facilitate this is the Problem-Solving laboratory (PSLab) model. The PSLab model teaches participants to systematically approach problems, with structured steps such as identifying the problem, collecting data, analyzing information, generating alternative solutions, and making appropriate decisions (Araiza-Alba et al., 2021). This systematic approach helps participants develop effective problem-solving skills that can be applied in various situations (Sutarno et al., 2017). In this regard, the integration of AR into the PSLab model becomes an innovation in improving the quality of science laboratory practices.

The goal of this research is to develop a model of an Augmented Reality-integrated Problem-Solving Laboratory (PSLab-AR). By combining easily accessible laboratory equipment with augmented reality technology, the practicum model product being developed is expected to provide new insights in training students' problem-solving skills and level of understanding, especially for abstract concepts. To keep this research on track, the following research questions were developed: (1) How does the design of PSLab-AR enhance students' problem-solving skills and level of understanding? (2) What is the effectiveness of disseminating PSLab-AR?

## Method

### *Research Design*

The research method used in this study is Research and Development (R&D) (Richey & Klein, 2014). The selection of this research model is in line with the main output of this study, which the development of a problem-solving laboratory model integrated with augmented reality technology called PSLab-AR. The research design used is the Define, Design, Develop, and Disseminate (4D), which this research design was developed by Thiagarajan (Marnah et al., 2022).

The first stage of this research is the define stage, which involves needs analysis. The analysis was conducted through interviews with elementary teachers to understand the laboratory activities typically conducted in the field, and by reviewing literature on laboratory models and innovative technologies that can enhance problem-solving skills and improve students' conceptual understanding. Additionally, content analysis was performed to determine which materials are suitable for the developed laboratory model. The second stage was is the design, we develop design of several phases of PS-AR lab framework. The stages are preparation, problem, exploration, measurement, data analysis, and conclusion. The development of this design refers to a skill to develop problem solving skills. The third phase was a development phase, which we developed PS-AR Lab framework, students' worksheet, and instruments of electricity concepts such as Ohm law, and current in closed circuits. Both PS-AR Lab framework, worksheet, and instruments were validated by experts in science education. The last phase was a dissemination phase, we implemented a learning process by using PS-AR lab and all worksheets and instruments developed in the participants. In this context, participants learned about concepts of Ohm laws and current flows in the closed-circuit using PS-AR lab.

### *Participants*

The participants in this study consist of three groups. The first group in the define stage comprises 2 elementary school teachers. They were chosen due to their experiences to teach elementary school students, which they had at least 10 or more years to teach five grade student elementary schools. The second group of participants, during the design and development stages, includes three experts from science education. They were chosen because they hold doctoral degree in science education so they had appropriate experiences to asses instruments test developed. Lastly, in the dissemination stage, there are 25 five-grade students aged between 11 and 12 years. The participants in this research were selected using purposive sampling techniques. The way participants were chosen just take a class as experimental group from three different class provided based on easiness and characteristics of students.

### *Instruments and Data Analysis*

The instrument used in define stage is a semi-structured interview with elementary school teachers to obtain data regarding the science laboratory activities traditionally conducted in schools. The data obtained is then analyzed using thematic analysis (Gumilar & Ismail, 2023a).

The instrument used in Design and Development Stage is a validation sheet for experts, prepared using the content validity index (CVI) method. This research employs CVI due to its several advantages, including its ease of calculation and comprehension and its provision of detailed information, as it can be used to measure the content validity of each item or instrument as a whole (Almanasreh et al., 2019). The data analysis of the CVI validation sheet consists of four validation considerations: scores of 4 (very relevant), 3 (quite relevant), 2 (somewhat relevant), and 1 (not relevant). These four assessment considerations are then converted into two consideration values as follows: a Score of 1 (relevant if the expert's assessment falls into categories 4 or 3) and a score of 0 (not relevant if the expert's assessment falls into categories 1 or 2). The average expert validation score indicators according to the CVI method are described in Table 1.

**Table 1. The number of experts and acceptable CVI scores (Shrotryia & Dhanda, 2019)**

| Number of experts | Acceptable CVI values |
|---|---|
| 2-5 experts | Should be 1 |
| 6-8 experts | At least 0.83 |
| > 9 experts | At least 0.78 |

At the Dissemination Stage, the instrument used was a concept understanding question consisting of 10 multiple choice questions. We performed a normalization gain analysis (Collazos et al., 2019) between pretest and post test scores to ascertain how well the PS-AR Lab practicum model has improved elementary school students' conceptual understanding. For every question, the score is 1 (one) for a right response and 0 (zero) for a wrong response. A maximum score of 100 and a minimum score of zero are obtained by converting the maximum possible score of 10 to a scale of 100. Afterwards, normalized gain scores were examined (Coletta & Steinert, 2020).

## Results and Discussion

### *Define Need Analysis*

The first stage in this research is the define stage. The necessity analysis in this research was conducted using field studies through semi-structured interviews with two teachers in the Garut Regency. Table 2 describes the results of interviews with teachers regarding the implementation of science laboratory practices conducted in schools in the Garut Regency.

Table 2. Transcription of the interview results

| Questions | Teacher Responses | |
|---|---|---|
| | Teacher-1 | Teacher-2 |
| How interested are students in participating in science laboratories? | Most of the students are enthusiastic about the laboratory, while some are not very enthusiastic. | Most students are very enthusiastic when they hear the term " laboratory," and they really want to conduct science laboratory experiments in the laboratory. |
| What science laboratory models do you often apply in the implementation of science laboratories? | The laboratory model used is the verification laboratory model. | The laboratory and student worksheet still use the cookbook laboratory. |
| Have the physics laboratory activities you conducted trained students in problem-solving? | Not yet, as science laboratories only use the verification laboratory model. | Not training yet. |
| What technologies have been integrated into science laboratories? | No technology has been used yet. | Never used technology before. |
| Have you ever integrated AR technology into science laboratories? | Not familiar with what AR technology is. | Never. |
| What difficulties do you encounter in facilitating physics laboratory activities? | The difficulties are due to the limited laboratory equipment and personal competence in integrating technology into the laboratory. | Lack of laboratory facilities and infrastructure. |

Based on the interview results, it is evident that the laboratories traditionally conducted in the field still utilize verification or cookbook laboratories. Certainly, this type of laboratory does not allow students to plan an idea (Husnaini & Chen, 2019). Moreover, this type of laboratory also demands that students behave as technicians, focusing on carrying out a series of procedures without attempting to interpret the obtained laboratory result(Abdullah et al., 2022; Gumilar & Ismail, 2023b).Other data findings indicate that teachers in schools have not yet implemented technology in laboratory activities. These findings are in line with other research findings, which indicate that only 25% of teachers have integrated technology into laboratories (Ismail, Setiawan, et al., 2019). However, the use of technology is crucial in learning, especially in the 21st century, as the utilization of technology can enhance the quality of education, increase student satisfaction, and reduce practical costs (Abdullah et al., 2022). The current situation in the field does not train problem-solving and the application of technology, which is not suitable for 21st-century learning. There are ten skills that students must possess in 21st-century learning, two of which are problem-solving skills and ICT literacy (Binkley et al., 2012). Therefore, innovation is necessary to bridge the gap in the field, meeting the demands of 21st-century learning, one of which involves developing an innovative laboratory model, namely PSLab-AR.

PSLab-AR is an innovative laboratory model that combines the problem-solving laboratory model with augmented reality technology. Problem-solving laboratories are an approach in education that aims to teach students how to effectively tackle problems. The key characteristics of problem-solving laboratories are that students are provided with a rich context of problems and they must apply theory to solve these issues. In the other siders, AR technology is the integration of real and virtual objects in the real environment, operating interactively in real-time, and with the integration of virtual objects in the real world. AR technology has the following characteristics: 1) Combining the real and virtual environment. 2) Operating interactively in real-time. 3) Integrating three dimensions (Azuma, 1997). AR technology is suitable for application in laboratory activities because there is no boundary between the real and virtual world.

Based on advantages of problem-solving laboratory and AR technology, PSLab-AR laboratory model has the following characteristics Exposing students to problems relevant to everyday life and utilizing AR technology to visualize concepts that cannot be seen with the naked eye. This laboratory model is designed to train students in problem-solving and understanding of concepts.

### *Design and Development of PSLab-AR*

***Design and Development framework of PSLab-AR:*** The next stage is to design the PSLab-AR framework. The design of this laboratory model consists of two sessions, the first being the pre-lab session conducted at home and the second being the laboratory activity session conducted in the laboratory. For the pre-lab session, there are two stages: preparation and problem statement. In the problem statement stage, real-world problems are presented, which are issues closely related to everyday life. The laboratory activity stage consists of four stages: exploration, measurement, data analysis, and conclusion. The integration of AR is implemented in the measurement stage. The initial PSLab-AR framework and the validation results from experts' judgments on the developed framework are shown in Table 3.

**Table 3. Responses of Initial framework of PSLab-AR**

| Session | Stage | Sub Stage | Judgment result | | | NoA | PoA |
|---|---|---|---|---|---|---|---|
| | | | E-1 | E-2 | E-3 | | |
| Pre-Lab | 1. Preparation | 1.1. Understanding the purpose of the laboratory | √ | √ | √ | 3 | 1 |
| | | 1.2. Reading the material | √ | √ | √ | 3 | 1 |
| | | 1.3. Answering conceptual questions | √ | √ | √ | 3 | 1 |
| | 2. Problem | 2.1. Studying the context of the real-world problem | √ | √ | √ | 3 | 1 |
| | | 2.2. Determining the tools and materials | - | - | √ | 1 | 1/3 |
| | | 2.3. Making predictions | √ | √ | √ | 3 | 1 |
| | | 2.4. Method Question | - | - | - | 0 | 0 |
| Lab activities | 3. Exploration | 3.1. Understanding the function of the tools | √ | √ | √ | 3 | 1 |
| | | 3.2. Composing the experimental procedure | √ | √ | √ | 3 | 1 |
| | 4. Measurement | Data collection (AR integration) | √ | √ | √ | 3 | 1 |
| | 5. Conclusion | Conclusion | √ | √ | √ | 3 | 1 |
| | 6. Preparation | Preparation | √ | √ | √ | 3 | 1 |

Note: E(expert), NoA (number of acceptance), and PoA (percentage of acceptance)

Based on the expert validation results shown in Table 3, out of the 12 stages and sub-stages validated by the experts, two sub-stages have scores below 1, namely the sub-stage of determining tools and materials and the method question sub-stage. For the sub-stage of determining tools and materials, the experts suggested not removing it but moving it to the exploration stage. As for the method question stage, the experts agreed that this sub-stage should be combined with the conceptual questions. Additionally, there was a suggestion from the experts to add a sub-stage of formulating the problem in the problem stage. The validation results were then revised, resulting in the final PSLab-AR framework as shown in Table 4.

**Table 4. Final framework of PSLab-AR**

| Session | Stages | Sub Stages |
|---|---|---|
| Lab | 1. Preparation | 1.1. Understanding the purpose of the laboratory |
| | | 1.2. Reading the material |
| | | 1.3. Answering conceptual questions |
| | 2. Problem | 2.1. Studying the context of the real-world problem |
| | | 2.2. formulating the problem |
| | | 2.3. Making predictions |
| Lab activities | 3. Exploration | 3.1. Determining tools and materials |
| | | 3.2. Understanding the function of the tools |
| | | 3.3. Composing the experimental procedure |
| | 4. Measurement | Data collection (AR integration) |
| | 5. Data analysis | Data analysis |
| | 6. Conclusion | Conclusion |

***Content development of PSLab-AR:*** The purpose of developing the PSLab-AR model is to train problem-solving skills and the level of students' conceptual understanding. In this laboratory model, problem-solving is trained in the pre-laboratory session by providing a narrative story close to everyday life, such as the problem of someone getting lost while hiking and needing an understanding of electrical concepts to turn on a flashlight, as shown in Figure 1.

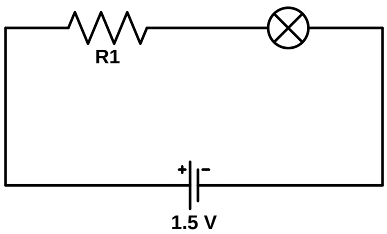
PSLab-AR is designed to improve students' understanding on a deeper level. Most students today only have a macroscopic understanding of concepts (Anam et al., 2023). Consequently, innovation is required to help students understand ideas on both a macroscopic and microscopic level (Kurnaz & Eksi, 2015). Using augmented reality technology, it is possible to visualize electron movement and improve comprehension of concepts that are microscopic. Because many students still think that electric current is the flow of positive charge from the battery's positive pole to its negative pole (Hernandez et al., 2022), it is necessary to visualize the behaviour of particle motion using augmented reality (AR) technology. In this research, an animation of the movement of electrons from negative charge to positive charge was developed. The sample of the problem provided in AR could be seen in the explanation presented in the below.

**Pre-lab session**

**Learn real-world problem**

***The context of the problem***

In a day, the middle of journey when hiking mountain. You are along with three your friends separated from the group and lost in jungle. To ask help on people surrounding the jungle, you have to on signal of Save Our Soul (SOS) that has specific feature of lamp. In the circuit of this device, there is a written information (4.5V-0.8A), so to on the lamp on this device requires a current at 0.8A. For this condition, you and your friends try to make a circuit that as presented in the figure in below.



After this circuit was made, the lamp is still not bright because the current flows in the circuit is too low to use a battery. To solve this problem, you need to arrange what solutions are needed to solve this problem?

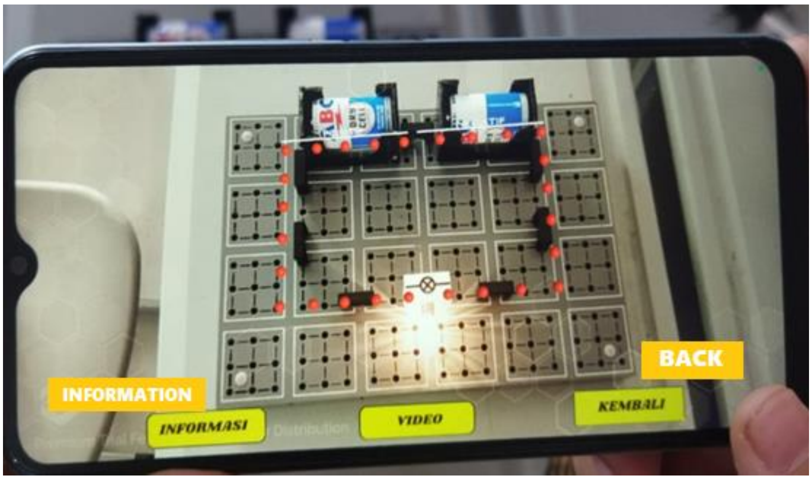



**Figure 1. Animation model of electron movement**

### *Dissemination of AR*

The results of the pretest and post-test scores for understanding the concepts in the electrical material are shown in this section. First, we provide the pretest and post-test descriptive data. This information is displayed in Table 5.

**Table 5. Descriptive statistics for understanding the concepts**

| Measurements | Experimental group | |
|---|---|---|
| | Pretest | Post-test |
| Number (N) | 25 | 25 |
| Minimum score | 70 | 100 |
| Maximum score | 40 | 70 |
| Average score | 54.8 | 82.4 |
| Standard deviation | 7.7 | 7.2 |

Based on Table 5, we can conclude that the posttest score (82.4) is higher than the pretest score (54.8) with an increase of 27.6. It's true, we can't conclude anything from the data so we have to test it using normalized gain scores to determine whether the increase is effective or not. By using the normalized gain formulation <g> proposed by (Molin et al., 2021), it was finally found that the average score of the experimental group (g=0.610) was in the medium category. This also strengthens empirical evidence that integrating AR-based learning media can facilitate students in increasing students' understanding of concepts in macroscopic and microscopic aspects.

## Conclusion

The purpose of this research is to develop an innovative practicum model designed according to the school's needs. Based on the analysis stage, it can be concluded that the situation in the field is still not ideal and does not meet the demands of 21st-century learning. Based on the results of interviews with teachers in the school, 21st-century skills have not yet been integrated into practicum activities, and technology has not been integrated either. Therefore, further research is needed to develop a practicum model that can train students' problem-solving skills and understanding levels. Based on the design stage, this practicum model is based on the PS Lab framework, integrating AR technology in the measurement stage. The initial design of PSLab-AR consists of 6 stages and 12 sub-stages. Based on the development stage, several improvements to the PSLab-AR framework were made to follow the recommendations of experts, resulting in a framework consisting of preparation stages (understanding practicum objectives, reading material, and answering questions), problem-solving (learning the context of the problem, formulating the problem, and making predictions), exploration (determining tools and materials, understanding tool functions, and creating procedures), measurement, data analysis, and conclusion. In this development stage, AR technology uses Polycom software to create marker-less markers and Unity software to create applications. After this stage, we have known that design of PSLab-AR was good enough to enhance students' problem-solving skills and level of understanding because students can be engaged to observe sub-microscopic phenomena provided in the application made.

Next to second research question, the effectiveness of disseminating PSLab-AR was effective enough, and this conclusion was obtained from the data normalized gain after the application was given to fifth grade students in elementary schools. We found that the normalized gain was 0.61, which it meant that the effectiveness of this type of laboratory activity was intermediate and this was obtained from dissemination stage. We found the conclusion that the PS-Lab AR practicum model was effective in increasing students' conceptual understanding.

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## References

Abdullah, S. I. N. W., Arokiyasamy, K., Goh, S. L., Culas, A. J., & Manaf, N. M. A. (2022). University students' satisfaction and future outlook towards forced remote learning during a global pandemic. *Smart Learning Environments*, *9*(1), 15. https://doi.org/10.1186/s40561-022-00197-8

Almanasreh, E., Moles, R., & Chen, T. F. (2019). Evaluation of methods used for estimating content validity. *Research in Social and Administrative Pharmacy*, *15*(2), 214–221. https://doi.org/10.1016/j.sapharm.2018.03.066

Anam, R. S., Gumilar, S., & Widodo, A. (2023). The Use of the Constructivist Teaching Sequence (CTS) to Facilitate Changes in the Visual Representations of Fifth-Grade Elementary School Students: A Case Study on Teaching Heat Convection Concepts. *International Journal of Science and Mathematics Education*. https://doi.org/10.1007/s10763-023-10358-x

Araiza-Alba, P., Keane, T., Chen, W. S., & Kaufman, J. (2021). Immersive virtual reality as a tool to learn problem-solving skills. *Computers & Education*, *164*, 104121. https://doi.org/10.1016/j.compedu.2020.104121

Azuma, R. T. (1997). A Survey of Augmented Reality. *Presence: Teleoperators and Virtual Environments*, *6*(4), 355–385. https://doi.org/10.1162/pres.1997.6.4.355

Balta, N., & Asikainen, M. A. (2019). A comparison of Olympians' and regular students' approaches and successes in solving counterintuitive dynamics problems. *International Journal of Science Education*, *41*(12), 1644–1666. https://doi.org/10.1080/09500693.2019.1624990

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., & Rumble, M. (2012). Defining Twenty-First Century Skills. In *Assessment and Teaching of 21st Century Skills* (pp. 17–66). Springer Netherlands. https://doi.org/10.1007/978-94-007-2324-5_2

Chang, S.-C., & Hwang, G.-J. (2018). Impacts of an augmented reality-based flipped learning guiding approach on students' scientific project performance and perceptions. *Computers & Education*, *125*, 226–239. https://doi.org/10.1016/j.compedu.2018.06.007

Coletta, V. P., & Steinert, J. J. (2020). Why normalized gain should continue to be used in analyzing preinstruction and postinstruction scores on concept inventories. *Physical Review Physics Education Research*, *16*(1), 010108. https://doi.org/10.1103/PhysRevPhysEducRes.16.010108

Collazos, C. A., Rojas, A., Castellanos, H., Beltrán, D., Collazos, C. A., Melo, D., Ruiz, I., Ostos, I., Sánchez, C. A., De-la-Hoz-Franco, E., Meléndez-Pertuz, F., & Mora, C. (2019). *Normalized Gain and Least Squares to Measure of the Effectiveness of a Physics Course* (pp. 66–77). https://doi.org/10.1007/978-3-030-24289-3_6

Fidan, M., & Tuncel, M. (2019). Integrating augmented reality into problem based learning: The effects on learning achievement and attitude in physics education. *Computers & Education*, *142*, 103635. https://doi.org/10.1016/j.compedu.2019.103635

Gumilar, S., & Ismail, A. (2023a). The representation of laboratory activities in Indonesian physics textbooks: a content analysis. *Research in Science & Technological Education*, *41*(2), 614–634. https://doi.org/10.1080/02635143.2021.1928045

Gumilar, S., & Ismail, A. (2023b). The representation of laboratory activities in Indonesian physics textbooks: a content analysis. *Research in Science & Technological Education*, *41*(2), 614–634. https://doi.org/10.1080/02635143.2021.1928045

Hernandez, E., Campos, E., Barniol, P., & Zavala, G. (2022). Phenomenographic analysis of students' conceptual understanding of electric and magnetic interactions. *Physical Review Physics Education Research*, *18*(2), 020101. https://doi.org/10.1103/PhysRevPhysEducRes.18.020101

Holmes, N. G., & Lewandowski, H. J. (2020). Investigating the landscape of physics laboratory instruction across North America. *Physical Review Physics Education Research*, *16*(2), 020162. https://doi.org/10.1103/PhysRevPhysEducRes.16.020162

Huang, S.-Y., Kuo, Y.-H., & Chen, H.-C. (2020). Applying digital escape rooms infused with science teaching in elementary school: Learning performance, learning motivation, and problem-solving ability. *Thinking Skills and Creativity*, *37*, 100681. https://doi.org/10.1016/j.tsc.2020.100681

Husnaini, S. J., & Chen, S. (2019). Effects of guided inquiry virtual and physical laboratories on conceptual understanding, inquiry performance, scientific inquiry self-efficacy, and enjoyment. *Physical Review Physics Education Research*, *15*(1), 010119. https://doi.org/10.1103/PhysRevPhysEducRes.15.010119

Ibáñez, M. B., Uriarte Portillo, A., Zatarain Cabada, R., & Barrón, M. L. (2020). Impact of augmented reality technology on academic achievement and motivation of students from public and private Mexican schools. A case study in a middle-school geometry course. *Computers & Education*, *145*, 103734. https://doi.org/10.1016/j.compedu.2019.103734

Ismail, A. (2021). Penerapan Model Pembelajaran Problem Solving Berbantuan Augmented Reality Untuk Meningkatkan Pemahaman Konsep Mahasiswa Pada Mata Kuliah Fisika Umum. *JURNAL PETIK*, *7*(2), 87–92. https://doi.org/10.31980/jpetik.v7i2.1017

Ismail, A., Festiana, I., Hartini, T. I., Yusal, Y., & Malik, A. (2019). Enhancing students' conceptual understanding of electricity using learning media-based augmented reality. *Journal of Physics: Conference Series*, *1157*, 032049. https://doi.org/10.1088/1742-6596/1157/3/032049

Ismail, A., Setiawan, A., Suhandi, A., & Rusli, A. (2019). Profile of physics laboratory-based higher order thinking skills (HOTs) in Indonesian high schools. *Journal of Physics: Conference Series*, *1280*(5), 052053. https://doi.org/10.1088/1742-6596/1280/5/052053

Kurnaz, M. A., & Eksi, C. (2015). An Analysis of High School Students' Mental Models of Solid Friction in Physics. *Educational Sciences: Theory & Practice*. https://doi.org/10.12738/estp.2015.3.2526

Marnah, Y., Suharno, & Sukarmin. (2022). Development of physics module based high order thinking skill (HOTS) to improve student's critical thinking. *Journal of Physics: Conference Series*, *2165*(1), 012018. https://doi.org/10.1088/1742-6596/2165/1/012018

Molin, F., Haelermans, C., Cabus, S., & Groot, W. (2021). Do feedback strategies improve students' learning gain?-Results of a randomized experiment using polling technology in physics classrooms. *Computers & Education*, *175*, 104339. https://doi.org/10.1016/j.compedu.2021.104339

Nita, L., Mazzoli Smith, L., Chancellor, N., & Cramman, H. (2023). The challenge and opportunities of quantum literacy for future education and transdisciplinary problem-solving. *Research in Science & Technological Education*, *41*(2), 564–580. https://doi.org/10.1080/02635143.2021.1920905

OECD. (2023). *PISA 2022 Results (Volume I)*. OECD. https://doi.org/10.1787/53f23881-en

Price, A., Salehi, S., Burkholder, E., Kim, C., Isava, V., Flynn, M., & Wieman, C. (2022). An accurate and practical method for assessing science and engineering problem-solving expertise. *International Journal of Science Education*, *44*(13), 2061–2084. https://doi.org/10.1080/09500693.2022.2111668

Richey, R. C., & Klein, J. D. (2014). *Design and Development Research*. Routledge. https://doi.org/10.4324/9780203826034

Shrotryia, V. K., & Dhanda, U. (2019). Content Validity of Assessment Instrument for Employee Engagement. *SAGE Open*, *9*(1), 215824401882175. https://doi.org/10.1177/2158244018821751

Sutarno, S., Setiawan, A., Suhandi, A., Kaniawati, I., & Putri, D. H. (2017). Keterampilan Pemecahan Masalah Mahasiswa Dalam Pembelajaran Bandul Fisis Menggunakan Model Problem Solving Virtual Laboratory. *Jurnal Pendidikan Fisika Dan Teknologi*, *3*(2), 164–172. https://doi.org/10.29303/jpft.v3i2.396

Wu, H.-K., Lee, S. W.-Y., Chang, H.-Y., & Liang, J.-C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education*, *62*, 41–49. https://doi.org/10.1016/j.compedu.2012.10.024