**Momentum: Physics Education Journal**
**8 (1), 2024, 120-132**
Available at: ejournal.unikama.ac.id/index.php/momentum
ISSN 2548-9127(print) | 2548-9135 (online)

# Development of augmented reality-based physics learning media on magnetic field

**Muhammad Sholeh*, Zeni Haryanto, Zulkarnaen**

Mulawarman University, Jl. Kuaro, Gn. Kelua, Samarinda 75119, Indonesia
e-mail: muhammad.sholeh16012002@gmail.com
* Corresponding Author.

*Received: 29 July 2023; Revised: 19 October 2023; Accepted: 17 December 2023*

**Abstract**: Physics is a science that is the basis for technological developments. Physics consists of many abstract concepts that make it difficult for students to understand—for example, magnetic field matter. Therefore, learning media could deliver information to students are needed. It allows teachers to design various learning media through dynamic representations such as Augmented Reality or AR. This study aims to determine the feasibility and response of students to AR-based learning media on the topic of magnetic field development. This research is R&D type with an ADDIE model. The validators are media experts, two material experts, and an educator validating upon feasibility test. Then, 96 12$^{th}$-grade students as research subjects in the product trial stage to obtain student responses. The feasibility test results from the media aspect are 91%, and the material aspect is 89%, which overall is 90% in the very feasible category. The product trial results found that student response was 85% in the very good category. Based on the study's results, AR-based learning media on magnetic fields is feasible to support physics learning.
**Keywords**: learning media; augmented reality; ADDIE; feasibility test; student responses

**How to Cite**: Sholeh, M., Haryanto, Z., & Zulkarnaen, Z. (2023). Development of augmented reality-based physics learning media on magnetic field. *Momentum: Physics Education Journal*, *8*(1), 120-132. https://doi.org/10.21067/mpej.v8i1.8576

## Introduction

Physics is a science that is the basis for technological developments. Physics is also a science in harmony with nature (Ismail et al., 2019). Therefore, physics is a basis for modern technology and development in science. Thus, physics is a valuable subject to study in high school/MA equivalent (Permendikbud, 2018). Meanwhile, there is a difference between the teacher's expectations and what students understand that happens in the field. The reason is that physics consists of abstract and complicated concepts, so students need to try to understand it. For instance, it cannot visualize directly or interact with, like touching or seeing, such as magnetic field material (Harun et al., 2020; Yilmaz & Batdi, 2021). In addition, by the 2018 OECD report, 55% of Indonesian students are below the second level of the maximum level, namely level five (OECD, 2019). This data shows that students' understanding of magnetic fields is still lacking.

The magnetic field is an abstract topic due to the difficulty of visualizing in determining the direction of the magnetic poles, the Lorentz force, and the magnetic field around the current wire (Hidayah et al., 2017). In addition, many students only know the concept of magnetic fields using hand rules but cannot explain it adequately (Özdemir &; Coramik, 2018). Learning books that only contain questions and formulas are one of the factors of magnetic fields becoming difficult to understand during learning (Nor &; Halim, 2021). In addition, magnetic fields are only imagined on the whiteboard during learning (Ibanez et al., 2017). There is a lack of learning media in which nothing can be visualized

(Salazar et al., 2020). Based on this, students still think physics is difficult and boring (Rizti Yovan &; Kholiq, 2021).

In recent years, developing the technology is increasing. Technology has a significant positive impact on education. Technology can involve students in various learnings that will assist students in processing information (Dasilva et al., 2019). With advances in technology, it provides opportunities for teachers to design various learning media through dynamic representation. Learning media is essential for delivering information in physics learning (Sundaygara et al., 2019). Learning media also helps to create an effective learning environment by incorporating text, images, animation, audio, and video into the classroom. Presenting information in visual and verbal forms simultaneously on learning media can encourage more effective learning (Altmeyer et al., 2020). Learning media can facilitate students' understanding of concepts. The magnetic fields, especially for science learning, require students to compile abstract concepts. Thus, to develop students' knowledge of the concept of magnetic fields that need to be assisted by technology.

There are immersive and interactive technologies that can produce information such as video, graphics, animation, and sound in the real world, called Augmented Reality or AR. This technology has become a trend in recent years in Educational technology (Salazar et al., 2020). AR technology has been applied in various fields of education and has recently begun attracting attention to magnetic fields with its abstract and complicated concepts (Fidan &; Tuncel, 2019). AR is one of the promising technologies to handle challenges in physics learning with its advantages. With this, AR can facilitate students in understanding the concept of magnetic fields. As a media, AR makes delivering magnetic fields that abstract to students simple and understood (Hafi &; Supardiyono, 2018). In addition, in the research of Techakosit (2015) regarding augmented reality on magnetic field material, it is still a prototype that has not been developed perfectly, and Yovan & Kholiq (2021) development does not involve students in research thath it cannot be fully said to be feasible. In addiition, the are still any 3d objects fot augmented reality only in the form of laboratory equipment for magnetic field that students themselves do not understand the concepts and applications of physics content correctly. Accordingly, this research developeds augmented reality-based learning media on magnetic field material that focuses on 3d objects that contain events and additional processes from applications in everyday lide that include responses in this development.

In schools, conventional learning media is still widely used and does not switch to more practical uses such as AR (Cai et al., 2017). So, this study intends to create AR learning media with the topic of magnetic fields. There has been a lot of development of AR learning media in the form of physics experiments. Still, there is a lack of development in the animation of the process of a phenomenon in a magnetic field (Cai et al., 2021). The planning of mastery of concepts in the right-hand rule is a novelty in this research. So AR can increase what knowledge students need in learning by adjusting to technology that develops in this era. Thus, researchers are eager to ensure the feasibility and response of students to AR learning media on the topic of magnetic fields developed.

## Method

This research is R&D type using the ADDIE model. This research's stages are analysis, product design, product development, product trial, and evaluation. The analysis stage consisted of 3 sub stages (i.e. material, user, and specification) which would be reference for designing product that appropriate needed and user. Then, proceed to product design where the result useful be overview to developing product. During developing product in this research use Unity3D, Vuforia, and Blender 3d as well as canva. Furthermore, product development stage in this research distributed questionnaires to validators, as many as five experts consisted of 2 media experts, 2 material experts and 1 teacher. In which media experts were learning media lecturer and augmenetd reality lecturer whereas material experts were electricity and magnetism lecturer and pure physics lecturer while teacher was physics teacher that the result merge of media and material aspect. In product trial stage involved 96 class XII high school students who had received magnetic field learning that the result be students reponse.

Evaluation stage as the last stage of this research in which evaluating the expert validation and the product trial result. The ADDIE's stages are shown in Figure 1.

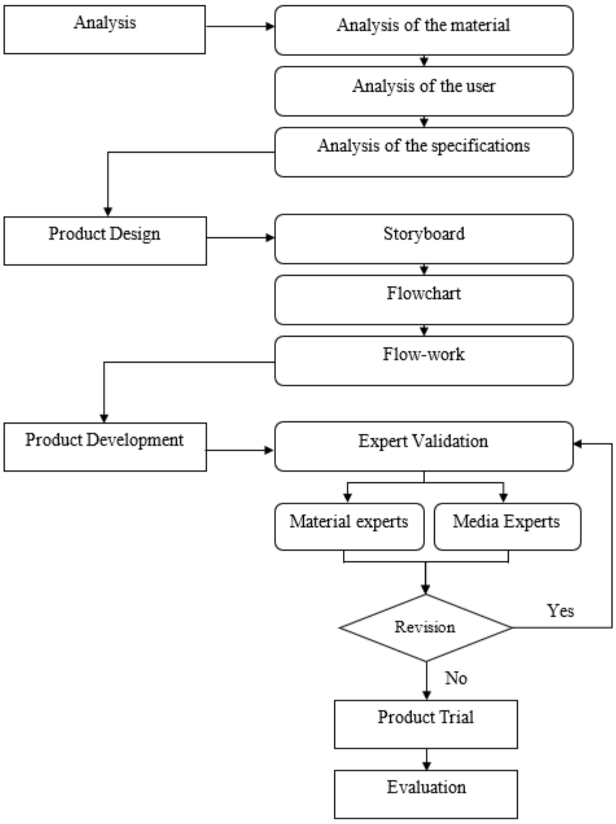


Figure 1. Research Stages

The questionnaire used is the adoption of BSNP (2008) in the feasibility of media aspect, material aspect, and student response. The questionnaire used is a closed questionnaire applying the Likert scale. The following are indicators to fullfill the feasibility of the learning media developed in the media aspect can be seen in Table 1.

Table 1. Media Experts assessment indicator grid

| Aspect | Indicator | Item |
|---|---|---|
| Graphic | Size | 1,2 |
| | Cover Design | 3,4 |
| | Content Design | 5,6,7,8 |
| | Object | 9,10,11 |
| | Navigation | 12,13,14,15 |
| Linguistic | Communicative | 1 |
| | Dialogue and Interactive | 2,3 |
| | Appropriateness to learner development | 4,5 |
| | Appropirateness with language rules | 6 |
| | Use of terms, symbols or icons | 7 |

In addition, the following are material aspect indicators of the learning media developed shown in Table 2.

Table 2. Material Experts assessment indicator grid

| Aspect | Indicator | Item |
|---|---|---|
| Content | Appropriateness content with learning objectives | 1,2 |
| | Accuracy of the material | 3,4,5,6,7,8 |

| Aspect | Indicator | Item |
|---|---|---|
| | Recency of the material | 9 |
| **Presentation** | Presentation technique | 1,2 |
| | Presentation support | 3,4,5 |
| | Coherence and flow of thought | 6 |
| **Contextual** | The nature of contextual | 1,2 |
| | Contextual components | 3,4,5,6 |

Whereas, the following are students responses indicators in product trial stage can be seen in Table 3.

**Table 3. Students Response assessment indicator grid**

| Aspect | Indicator | Item |
|---|---|---|
| **Response** | Material | 1,2,3,5, |
| | Graphic | 6,7,8,9 |
| | Attraction | 10,11,12,13 |

The alternative answers given to experts are very poor to very good, and for students who strongly disagree to agree strongly, both have five alternative answers with a score of 1 - 5. The equation to calculate the percentage of feasibility tests and student responses to the developed products using equation (1)

$$\text{Percentage} = \frac{\sum \text{JV}}{\sum \text{STV}} \times 100\% \quad (1)$$

Information:
Percentage = percentage of due diligence results and student responses
$\sum$JV= Total number of answer choices
$\sum$STV= Score Maximum
(Febrianti, 2016)

Five experts' percentage results of the questionnaire assessment can refer to predetermined categories—the percentage outcome categories of experts presented in Table 4.

**Table 4. Feasibility Test Result Category (Yovan & Kholiq, 2021)**

| Percentage | Category |
|---|---|
| **0% – 20%** | Very Less Feasible |
| **20% - 40%** | Less Feasible |
| **40% - 60%** | Enough |
| **60% - 80%** | Feasible |
| **80% - 100%** | Very Feasible |

Meanwhile, the percentage results of the questionnaire assessment by 96 students refer to predetermined categories—the percentage outcome categories of the students presented in Table 5.

**Table 5. Student Response Result Category (Nor & Halim, 2021)**

| Percentage | Category |
|---|---|
| **16% - 37%** | Very Poor |
| **37% - 58%** | Poor |
| **58% - 79%** | Good |
| **79% - 100%** | Very Good |

## Results and Discussion

This research produces AR physics learning media products consisting of books and Android applications. The development of this product carries out stages following ADDIE. Following are the exposure of the results during the ADDIE stage:

### *Analysis Stage*

The analysis was conducted by analyzing the topic of magnetic fields in the 2013 curriculum, whose main topics consisted of magnetic fields around electric currents, magnetic fields on straight wire currents, solenoids, toroids, and magnetic forces. The main topics are into 18 sub-topics. This preparation compiles concrete topics to abstracts by studying literature from 7 University Books. On the other hand, material selection is according to topics that require strenuous effort and simple real-life examples that are difficult to find (Guisasola et al., 2004; Liu et al., 2021). It is reasonable that the magnetic field learns to calculate the strength of the magnetic field and the direction of the invisible magnetic field itself ((Fatimatuzzahroh &; Parno, 2022; IOP, 2023). For example, such as misconceptions about the direction of Lorentz force vectors, magnetic fields, and electric currents, as well as the concepts of Ampere's Law and Biot-Savart's Law, which are significant problems in magnetic field learning (Kade* et al., 2022). Applications of magnetic fields such as speakers, electric motors, galvanometers and the aurora borealis are difficult to demonstrate in the classroom as an application in magnetic fields in everday life. These are complex events which can take a long time and are expensive to demonstaret and hard for students to understanding (Kesonen et al., 2011). Then, there are many mistakes in the use of the right hand rule both right hand rule 1, right hand rule 2, right hand rule 3 wehre both students can make mistakes and misconceptions in their use and application in various cases. Thus, 18 sub-topics are magnetic fields and the direction of magnetic lines, the difference between magnetic pole and electric charge, uniform magnetic field, the direction of the magnetic field perpendicular to the page, the magnetic field on the circular wire, the magnetic field on the straight wire. right hand rule 1, the magnetic field on the solenoid, the right hand rule on the solenoid, the beel process due to the magnetic field, toroida, right hand rule 2, eletcric motor process, galvanometer process, right hand rule 3, aurora borealis process, and speaker process. The sub-topic is an analysis of user need for student misconceptions in learning magnetic fields.

### *Product Design Stage*

Product design generates storyboards and activity diagrams. This stage is an optimization of the interface design. Storyboards for apps and books are in Figure 2.


(a)


(b)

**Figure 2. AR-based learning media product storyboard: (a) Application Storyboard (b) Book Storyboard**

In addition, the product design activity diagram, which provides an overview of the application process from installation to the exit of the application, is in Figure 3.

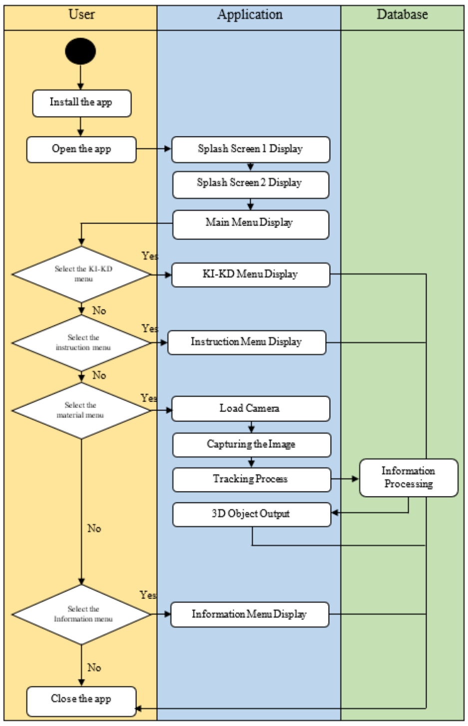

Figure 3. App activity diagram

The activity diagram illustrates that When started and the camera focuses on Books (target image), AR is displayed. Then, a little information was added to the target image, which some researchers say is more convenient for users (Yulianti et al., 2023). On the other hand, this book product consists of 25 pages from the cover to the glossary and 18 magnetic field sub-topics with a target image for each page. The size of the book product is A5 by ISO standards.

### *Product Development Stage (Feasibility Test)*

In the feasibility Test, the product development stage by validating the product to 5 validators, including media experts, material experts, and educators. The percentage of each validator is in Table 6.

Table 6. Feasibility Test Percentage of Each Validator

| No | Validator | Percentage |
|---|---|---|
| **1** | Media Expert 1 | 93% |
| **2** | Media Expert 2 | 86% |
| **3** | Material Expert 1 | 90% |
| **4** | Material Expert 2 | 86% |
| **5** | Educator | 95% |
| | **Overall** | 90% |

In Table 6, according to the Yovan &; Kholiq (2021) category, it is found that the overall percentage of the five validators is in the very feasible category range. The percentage by educators is the highest feasibility test result of 95%, while the percentage by media expert two and material expert 2 is the lowest due diligence result at 86%. In addition, the feasibility test results for each aspect are in Figure 3.

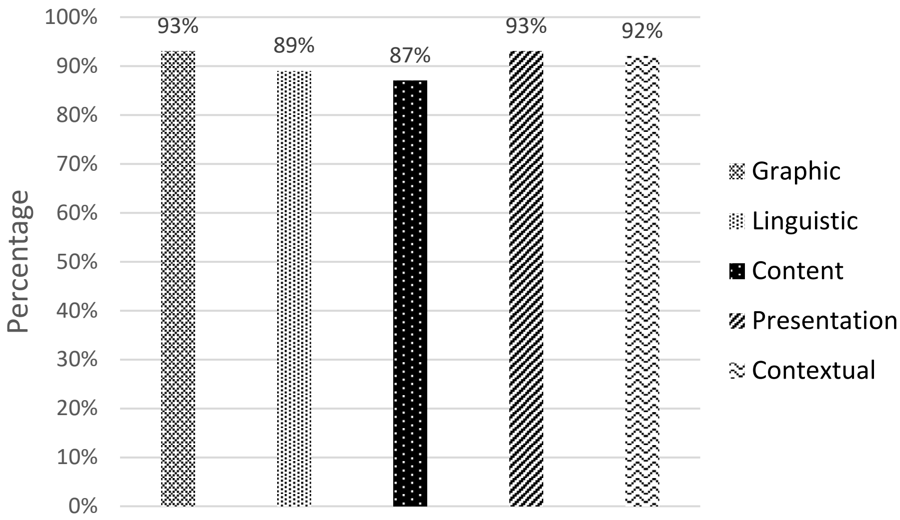


**Figure 4. The percentage of each aspect**

Figure 4 presents five aspects of the feasibility test of AR learning media products on magnetic fields. The graphic and presentation aspects get the highest percentage of 93%. However, the content aspect gets the lowest percentage at 87%. In previous studies, aspects of graphics and presentation also had a high percentage of feasibility test results (Permana et al., 2019). In addition, indicators from each aspect of media, namely graphics, and language, are calculated as a percentage of feasibility. The results of the Feasibility Test on the media aspect are in Table 7.

**Table 7. Percentage of Each Media Aspect Indicator**

| No | Indicator | Average | | | Percentage |
|---|---|---|---|---|---|
| | | Media Expert 1 | Media Expert 2 | Educator | |
| 1 | Size | 4.5 | 5.0 | 5.0 | 97% |
| 2 | Cover Design | 4.5 | 4.5 | 5.0 | 93% |
| 3 | Content Design | 4.8 | 4.8 | 5.0 | 97% |
| 4 | Object | 4.7 | 4.3 | 5.0 | 93% |
| 5 | Navigation | 4.5 | 3.8 | 4.8 | 87% |
| 6 | Communicative | 5.0 | 4.0 | 4.0 | 87% |
| 7 | Dialogue and Interactive | 4.5 | 4.5 | 4.5 | 90% |
| 8 | Suitability to Student Outgrowth | 4.5 | 4.0 | 5 | 90% |
| 9 | Compliance with Language Rules | 5.0 | 4.0 | 4.0 | 87% |
| 10 | Use of terms, symbols, or icons | 5.0 | 4.0 | 4.0 | 87% |

All indicators in Table 7 are in the very decent category range. This size and design indicator is the highest due diligence result, with a percentage of 97%. These results align with previous studies, where results on content design had the highest percentage (Danik et al., 2020). Factors such as book size according to ISO standards and according to the amount of content presented are the reasons size indicators have the highest percentage. In addition, no exaggeration the use of typeface, covers that match the content, the layout of titles, page numbers, and appropriate illustrations that do not interfere with students' understanding are the reasons design indicators also get the highest percentage. In addition, indicators for material aspects, namely content, presentation, and contextual, are also calculated as supported factors. The percentage of the feasibility of indicators on the material aspect is in Table 8.

Table 8. Percentage of Each Material Aspect Indicator

| No | Indicator | Average | | | Percentage |
|---|---|---|---|---|---|
| | | Material Expert 1 | Material Expert 2 | Educator | |
| 1 | Compatibility of the material with Standard of Competencies and Basic Competencies | 4.0 | 4.0 | 4.5 | 83% |
| 2 | Material Suitability | 4.7 | 4.0 | 4.7 | 89% |
| 3 | Material Updates | 4.0 | 4.0 | 5.0 | 86% |
| 4 | Presentation Techniques | 5.0 | 4.0 | 4.5 | 90% |
| 5 | Presentation Supports | 5.0 | 5.0 | 5.0 | 100% |
| 6 | Coherence of Students' Thought | 4.0 | 4.0 | 4.0 | 80% |
| 7 | Contextual Facts | 5.0 | 4.0 | 5.0 | 93% |
| 8 | Contextualized Components | 4.0 | 4.8 | 5.0 | 92% |

Overall, the indicators are the very feasible category in Table 8, except for the coherence of students' thought indicators. On the other hand, the presentation supports the indicator with the highest percentage of 100%. The consistency of systematics in presenting the material, the presentation of concepts that are coherent from concrete to abstract, the presence of prefaces, glossaries, and bibliography relevant to the topic of magnetic fields, as well as the integrity of meaning in the paragraph are factors in the feasibility indicators of presentation support. Meanwhile, the indicator of coherence of students' thought flow is the lowest indicator for material aspects, which is 80%. This result is because wholeness in the meaning of a paragraph still requires effort to understand it. In line with previous research, the obstacle in understanding a sentence described in AR media products in previous research (Nandyansah et al., 2020). Thus, based on two aspects, media and material obtained an overall percentage of 91% and 89%, of which 91% are in the very feasible category range. With this, AR learning media on magnetic fields can move to the product trial stage. The final result of this product is called MeManAR or Augmented Reality Magnetic Field. The logo and cover are in Figure 5.


Figure 5. MeManARs' logo and cover

### *Product Trial Stage (Students Response)*

Students follow the directions in the implementation of product trials, namely 1) download via scanning the QR code and install the MeManAR application, 2) run the application/open the application, 3) select the material button on the main menu page (Sulistyowati et al., 2021). Then, students are encouraged to fill out the response questionnaire given. The calculation of the student responses questionnaire results is the percentage of student responses. The results of product trials for each indicator are in Table 9.

**Table 9. Percentage of Each Response Indicator**

| No | Indicator | Percentage |
|---|---|---|
| **1** | Material | 84% |
| **2** | Presentation | 89% |
| **3** | Interest | 83% |
| | **Students Response** | 85% |

All three indicators of student response are in the very good category in Table 9. This result is in line with the results of overall product trials that the products developed in the category range are very good for the student response (Rohmaniyah et al., 2017). Presentation indicators get the highest percentage of student responses because factors such as sentences and language are easy to understand and straightforward, fonts that are not confusing to read, and attractive AR learning media products appear. In line with the due diligence results, graphs have the highest percentage. Thus, it is that the results of student responses align with the feasibility test results. Thus, the overall percentage of student responses of 83% who are in the range of categories is very good. Students welcome it by giving a positive attitude toward the existence of this AR learning media as a support in learning (Nusroh et al., 2022). In addition, students can understand a concept with magnetic field phenomena that are usually only found in pictures in books or on whiteboards. Students can use MeManAR and become an interactive media because it can interact with its content (Sulistyowati et al., 2018). With the positive student response, this AR can be combined with various interactive learning methodology activities such as flipped classroom or small group discussion (Jesionkowska et al., 2020). This student response may be due to AR providing a unique way to transmit information to students to understan magnetic fields (Villanueva et al., 2021) This also means that AR can provide motivation during learning (Zafeiropoulou et al., 2021).  In addition, AR also provides experience to students both adding digital literacy skills and interpreting the occurrence of phenomena caused by magnetic fields (Sandoval Pérez et al., 2022). Thus, the product that has been developed gives positive student responses because of the advantages presented by AR.

**Figure 6. Product Trial Process by Students**

### *Evaluation Stage (Students Response)*

The implementation of the evaluation stage is after feasibility tests and product trials on products that have been developed (Sumardani et al., 2019). The evaluation stage aims to provide quality improvement in products (Lubis &; Herlina, 2022). Validators and students provide evaluations at the product development and trial stages. Evaluation at the development stage, validators offer suggestions for improving the quality of MeManAR for several things that need to be changed or added (Badryatusyahryah et al., 2020). In addition, suggestions and comments were also on student responses at the trial stage of MeManAR products on magnetic fields. Comments and suggestions by students are in Table 10.

Table 10. Student Comments and Suggestions

| Student | Comments and Suggestions |
|---|---|
| **Student 1, Student 24, Student 27** | We recommend that it also provide for IOS as well. I suggest this application be accessed on any smartphone to make it easier. |
| **Student 10 and Student 11** | The application is good and easy to understand and hopefully can be enhanced. It can increase my enthusiasm for learning and fun. |
| **Students 15** | In my opinion, with this AR media, we become more enthusiastic and not quickly bored and for advice, hopefully in the future, not only for other magnetic field materials can also. |
| **Students 25** | This tool helps me to understand the meaning of the images in the material and facilitates the learning system. |

In addition, the evaluation also considers smartphone specifications. Android type, screen resolution, and storage space are specifications evaluating product feasibility. MeManAR is obtained to run smoothly and successfully for various devices (Dengen et al., 2019). The types of device specifications are in Table 11.

Table 11. Smartphone Specifications of Users

| No | Types of Smartphones | Specifications | Install | Navigation | Scan Marker |
|---|---|---|---|---|---|
| 1 | Samsung Galaxy A30s | **Android 9.0<br>25MP Camera<br>720 x 1560 pixels<br>4GB RAM** | **Succeed** | **Succeed** | **Succeed** |
| 2 | Xiaomi Poco X3 GT | **Android 11.0<br>64MP Camera<br>1080 x 2400 pixels<br>8GB RAM** | | | |
| 3 | OPPO CPH2083 | **Android 9.0<br>13MP Camera<br>720 x 1520 pixels<br>3GB RAM** | | | |
| 4 | Samsung Galaxy A23 | **Android 12.0<br>50MP Camera<br>1080 x 2408 pixels<br>4GB RAM** | | | |
| 5 | Vivo Y53s | **Android 11.0<br>64MP Camera<br>1080 x 2408 pixels<br>8GB RAM** | | | |

Overall, MeManAR is in the very feasible category and received a very good student response. MeManAR has the advantage of seeing the entire process of phenomena or concepts from various points of view, which can help students' spatial intelligence (A/L Eh Phon et al., 2019; Prahanı et al., 2022). Adding audio to MeManAR can improve students' understanding of concepts with various senses in magnetic field learning. According to feasibility by Ernawati (2017), subject matter, namely the suitability of the material with the needs and initial goals of the product, has received a percentage of 89% in the very good category. Second, the auxiliary information about parts such as the introduction, usage guide, and others gets a perfect percentage of 100%. The third is affective considerations, which can motivate to learn more, supported by the percentage of student responses to the interest indicator of 83% with a very good category. Fourth, the interface aspect, namely display, text, animation, and graphics, gets a percentage of 93% in the aspect of graphic validity and product presentation. Fifth, navigation aspects of 87% support navigation that regarding easy and consistent use. Then, contextual components of 92%, where the contextual facts get a percentage of 93%, and the contextual component of 92%, which is in the very feasible category, support the pedagogy aspect in the capacity of learning strategies. Finally, the robustness or durability of products that do not error is also supported successfully in using types of smartphones with different specifications starting from the conventional to the latest, so that the results and theory of this product can be said to be feasible to apply in magnetic field learning.

## Conclusion

The feasibility test results showed a percentage of 91% for the media aspect and 89% for the material aspect; overall, 90% in the category range is very feasible. The percentage of product trials showed 85% of student responses in the category range is very good. By the study results, MeManAR can be an alternative learning medium to support magnetic field learning.

## References


A/L Eh Phon, D. N., Abdul Rahman, M. H., Utama, N. I., Ali, M. B., Abd Halim, N. D., & Kasim, S. (2019). The Effect of Augmented Reality on Spatial Visualization Ability of Elementary School Student. *International Journal on Advanced Science, Engineering and Information Technology*, *9*(2), 624. https://doi.org/10.18517/ijaseit.9.2.4971

Altmeyer, K., Kapp, S., Thees, M., Malone, S., Kuhn, J., & Brünken, R. (2020). The use of augmented reality to foster conceptual knowledge acquisition in STEM laboratory courses—Theoretical background and empirical results. *British Journal of Educational Technology*, *51*(3), 611–628. https://doi.org/10.1111/bjet.12900

Badryatusyahryah, B., Ernawati, I. R., & Hidayat, M. (2020). Augmented Reality in Static Electrical Materials for High School. *Jurnal Pembelajaran Sains*, *4*(1).

Cai, S., Chiang, F. K., Sun, Y., Lin, C., & Lee, J. J. (2017). Applications of augmented reality-based natural interactive learning in magnetic field instruction. *Interactive Learning Environments*, *25*(6), 778–791. https://doi.org/10.1080/10494820.2016.1181094

Cai, S., Liu, C., Wang, T., Liu, E., & Liang, J. C. (2021). Effects of learning physics using Augmented Reality on students' self-efficacy and conceptions of learning. *British Journal of Educational Technology*, *52*(1), 235–251. https://doi.org/10.1111/bjet.13020

Danik, E., Sarwi, & Wiwi, I. (2020). *Media Development of Water Cycle Augmented Reality Media Based on ICT of Scientific Approach for Grade V*. *443*(Iset 2019), 690–693. https://doi.org/10.2991/assehr.k.200620.141

Dasilva, B. E., Ardiyati, T. K., Suparno, Sukardiyono, Eveline, E., Utami, T., & Ferty, Z. N. (2019). Development of Android-based Interactive Physics Mobile Learning Media (IPMLM) with scaffolding learning approach to improve HOTS of high school students. *Journal for the Education of Gifted Young Scientists*, *7*(3), 659–681. https://doi.org/10.17478/jegys.610377

Dengen, N., Pakpahan, H. S., Putra, G. F., Firdaus, M. B., Wardhana, R., & Tejawati, A. (2019). An Augmented Reality Model Physical Transformation Learning. *ICEEIE 2019 - International Conference on Electrical, Electronics and Information Engineering: Emerging Innovative Technology for Sustainable Future*, 255–259. https://doi.org/10.1109/ICEEIE47180.2019.8981444

Fatimatuzzahroh, I., & Parno, P. (2022). Needs Analysis of Class XII Students of MA Raudlatul Ulum on the Development of a Recitation Program as an Interactive Learning Media on Magnetic Field Material. *Jurnal Pendidikan Fisika Dan Teknologi*, *8*(1), 90–96. https://doi.org/10.29303/jpft.v8i1.3508

Febrianti, R. (2016). Pengembangan Media Pembelajaran Berbasis Augmented Reality Pada Kompetensi Dasar Memahami Rangkaian Multiplexer, Decoder, Flip-Flop Dan Counter Kelas X Smk Negeri 2 Surabaya. *It-Edu*, *1*(01), 48–56.

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

Guisasola, J., Almudí, J. M., & Zubimendi, J. L. (2004). Difficulties in learning the introductory magnetic field theory in the first years of university. *Science Education*, *88*(3), 443–464. https://doi.org/10.1002/sce.10119

Ibanez, M. B., De Castro, A. J., & Kloos, C. D. (2017). An Empirical Study of the Use of an Augmented Reality Simulator in a Face-to-Face Physics Course. *Proceedings - IEEE 17th International Conference on Advanced Learning Technologies, ICALT 2017*, 469–471. https://doi.org/10.1109/ICALT.2017.105

IOP. (2023). *Exploring magnets - Teaching and learning issues*. IOPSpark. https://spark.iop.org/collections/exploring-magnets-teaching-and-learning-issues-0

Jesionkowska, J., Wild, F., & Deval, Y. (2020). Active learning augmented reality for steam education—a case study. *Education Sciences*, *10*(8), 1–15. https://doi.org/10.3390/educsci10080198

Kade*, A., Supriyatman, S., Darsikin, D., & Zaky, M. (2022). Analysis of Physics Education Students' Difficulties in Electricity and Magnetic Concepts in The Covid-19 Pandemic. *Jurnal Pendidikan Sains Indonesia*, *10*(4), 766–777. https://doi.org/10.24815/jpsi.v10i4.26222

Kesonen, M. H. P., Asikainen, M. A., & Hirvonen, P. E. (2011). University students' conceptions of the electric and magnetic fields and their interrelationships. *European Journal of Physics*, *32*(2), 521–534. https://doi.org/10.1088/0143-0807/32/2/023

Liu, Q., Yu, S., Chen, W., Wang, Q., & Xu, S. (2021). The effects of an augmented reality based magnetic experimental tool on students' knowledge improvement and cognitive load. *Journal of Computer Assisted Learning*, *37*(3), 645–656. https://doi.org/10.1111/jcal.12513

Lubis, R., & Herlina, M. (2022). Needs Analysis of Augmented Reality Development on Microbiology Practical Guide of Virus Material. *Al-Ishlah: Jurnal Pendidikan*, *14*, 2043–2048. https://doi.org/10.35445/alishlah.v14i1.1161

Nor, M., & Halim, L. (2021). Analysis of physics learning media needs based on mobile augmented reality (AR) on global warming for high school students. *Journal of Physics: Conference Series*, *2126*(1). https://doi.org/10.1088/1742-6596/2126/1/012009

Nusroh, H., Khalif, M. A., & Saputri, A. A. (2022). Developing Physics Learning Media Based on Augmented Reality to Improve Students' Critical Thinking Skills. *Physics Education Research Journal*, *4*(1), 23–28. https://doi.org/10.21580/perj.2022.4.1.10912

Özdemir, E., & Coramik, M. (2018). Reasons of student difficulties with right-hand rules in electromagnetism. *Journal of Baltic Science Education*, *17*(2), 320–330. https://doi.org/10.33225/jbse/18.17.320

Permana, A. H., Muliyati, D., Bakri, F., Dewi, B. P., & Ambarwulan, D. (2019). The development of an electricity book based on augmented reality technologies. *Journal of Physics: Conference Series*, *1157*(3). https://doi.org/10.1088/1742-6596/1157/3/032027

Prahanı, B. K., Saphıra, H. V., & Wıbowo, F. C. (2022). Trend and Visualization of Virtual Reality & Augmented Reality in Physics Learning From 2002-2021. *Journal of TUrkish Science Education*, *19*(4), 1096–1118.

Rizti Yovan, R. A., & Kholiq, A. (2021). Pengembangan Media Augmented Reality Untuk Melatih Keterampilan Berpikir Abstrak Siswa SMA pada Materi Medan Magnet. *PENDIPA Journal of Science Education*, *6*(1), 80–87. https://doi.org/10.33369/pendipa.6.1.80-87

Rohmaniyah, I. A., Jurusan, M., Fisika, P., Negeri, U., Yogyakarta, U. N., Reality, A., & Global, P. (2017). *Pengembangan Media Pembelajaran Fisika Berbasis Augmented Reality pada Materi Pemanasan Global untuk Meningkatkan Hasil Belajar Peserta Didik Kelas XI SMA / MA The Development of Augmented Reality-Based Physics Learning Media on Global Warming Materials t*. 1–6.

Salazar, J. L. H., Pacheco-Quispe, R., Cabeza, J. D., Salazar, M. J. H., & Cruzado, J. P. (2020). Augmented reality for solar system learning. *2020 Ieee Andescon, Andescon 2020*, 0–3. https://doi.org/10.1109/ANDESCON50619.2020.9272008

Sandoval Pérez, S., Gonzalez Lopez, J. M., Villa Barba, M. A., Jimenez Betancourt, R. O., Molinar Solís, J. E., Rosas Ornelas, J. L., Riberth García, G. I., & Rodriguez Haro, F. (2022). On the Use of Augmented Reality to Reinforce the Learning of Power Electronics for Beginners. *Electronics (Switzerland)*, *11*(3), 1–14. https://doi.org/10.3390/electronics11030302

Sulistyowati, P., Ananda, N. S., & Hudha, M. N. (2021). Developing an instructional media based on Augmented Reality animation for 3R topic (Reduce, Reuse, and Recycle) of thematic learning. *IOP Conference Series: Materials Science and Engineering*, *1098*(3), 032111. https://doi.org/10.1088/1757-899x/1098/3/032111

Sulistyowati, P., Setyaningrum, L., Kumala, F. N., & Hudha, M. N. (2018). Android-based monitoring applications of students' learning outcomes. *IOP Conference Series: Materials Science and Engineering*, *434*(1), 0–6. https://doi.org/10.1088/1757-899X/434/1/012036

Sumardani, D., Putri, A., Ramadhan, Z., Bakri, F., & Muliyati, D. (2019). Augmented Physics' Lab: Magnetic Field Use Virtual Learning Media for 21st Century Students. *Jurnal Pembelajaran Fisika*, *8*(1), 61–70. https://doi.org/10.23960/jpf.v8.n1.202007

Sundaygara, C., Pratiwi, H. Y., & Hudha, M. N. (2019). Pengembangan bahan ajar media pembelajaran fisika dengan pendekatan multi representasi untuk meningkatkan kemampuan pembuatan alat-alat praktikum calon guru fisika. *Momentum: Physics Education Journal*, *2*(2), 86–93. https://doi.org/10.21067/mpej.v2i2.2709

Villanueva, A., Liu, Z., Kitaguchi, Y., Zhu, Z., Peppler, K., Redick, T., & Ramani, K. (2021). Towards modeling of human skilling for electrical circuitry using augmented reality applications. *International Journal of Educational Technology in Higher Education*, *18*(1). https://doi.org/10.1186/s41239-021-00268-9

Yulianti, E., Mustikasari, V. R., Muhlisin, N., Farahwahidah, N., Rahman, A., & Phang, F. A. (2023). *An augmented reality-based science book for junior high school students : Case study on environmental pollution and global warming topics An Augmented Reality-Based Science Book for Junior High School Students : Case Study on Environmental Pollution and G*. *060010*(January).

Zafeiropoulou, M., Volioti, C., Keramopoulos, E., & Sapounidis, T. (2021). Developing physics experiments using augmented reality game-based learning approach: A pilot study in primary school. *Computers*, *10*(10). https://doi.org/10.3390/computers10100126