Needs Analysis and Design of Digital Electronics AR with the PjBL Model

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Abstract: The rapid advancement of educational technology, particularly in vocational education, has opened new opportunities to address learning challenges in complex technical subjects. This study aims to analyze the needs and design Augmented Reality (AR)-based learning media for the Digital Electronics subject using the Project-Based Learning (PjBL) model. The AR media is designed to assist students in understanding abstract and complex concepts in Digital Electronics, such as logic circuits and digital systems, in an interactive and visual manner. The research method employed is Research and Development (R&D) following the ADDIE development model, which includes the stages of analysis, design, development, implementation, and evaluation. Needs analysis results indicate that students face difficulties in understanding digital electronics concepts without additional visualization. Furthermore, both teachers and students expressed high interest in using AR technology to support a more effective and engaging learning process. PjBL-based AR media is expected to enhance students' conceptual understanding and practical skills in Digital Electronics, as well as provide a deeper learning experience through applicative projects. By demonstrating this synergy between AR and PjBL, the study establishes a foundation for integrating immersive technologies into science and technology education, thereby enriching conceptual understanding while cultivating critical thinking, creativity, and other essential 21st-century competencies.

Keywords: Augmented reality; Digital electronics; Learning design; Needs Analysis; Project-based learning

Introduction

Educational technology continues to advance rapidly, particularly in the field of vocational education. Amidst the developments of Industry 4.0, the demand for practical skills in digital electronics engineering has become increasingly urgent. In this context, Augmented Reality (AR) has been recognized as an effective learning aid (Bacca et al., 2019; Hasanah et al., 2023; Muslim et al., 2024; Sandoval Pérez et al., 2024). AR technology integrates the real world with virtual objects, enabling students to visualize abstract technical concepts (Degner et al., 2022; Hafizhah & Setyasto, 2024). Research by Pipattanasuk et al. (2020), and Suryanti et al. (2020) demonstrates that AR provides a more interactive and immersive learning experience, assisting students in better understanding complex technical concepts. This is particularly relevant in digital electronics education, where students often face challenges in grasping interactive technical ideas (Singh & Ahmad, 2024). Moreover, Pipattanasuk et al. (2020) highlight that the broad application of AR technology in the education sector can accelerate the transition towards more

technology-driven and collaborative learning environments.

Previous studies have demonstrated the effectiveness of AR in enhancing learning across various disciplines, particularly in subjects requiring strong technical visualization. Research by Evangelista et al. (2022), Suryanti et al. (2020), and Zhou et al. (2020) reported that AR can improve students' understanding of complex material, especially in technical fields. Studies by Buchner et al. (2023), Kaluku et al. (2022), and Rusli et al. (2022) also highlighted that AR makes learning more engaging and helps students grasp complex concepts more quickly.

However, there remains a limited number of studies specifically addressing the use of AR in digital electronics learning within a Project-Based Learning (PjBL) framework. Waskita et al. (2023) found that incorporating AR into PjBL offers students a deeper learning experience while fostering collaborative skills. Furthermore, additional research is needed to explore how AR can be integrated with PjBL to enhance students' technical skills and critical thinking abilities (Câmara Olim et al., 2024; Hasanah et al., 2023; Suryanti et al., 2020).

This study aims to analyze students' learning needs in the field of digital electronics and develop an AR design that can be integrated with the PjBL model. It examines how the use of AR can enhance students' understanding of electronic concepts and how integrating this technology into PjBL can improve students' practical skills, critical thinking, and creative abilities. This research is expected to provide new insights into how educational technology can be optimized to improve the quality of vocational education, particularly in the context of Industry 4.0.

Studies by Dayagdag et al. (2019), Elmunsyah et al. (2019), Pipattanasuk et al. (2020), Tuwoso et al. (2021) also emphasize the importance of AR-based educational technology in expanding contextual learning approaches, particularly within vocational education environments.

Degner et al. (2022) reported that AR helps students visualize electronic circuits and gain a deeper understanding of component operations. Additionally, the integration of AR into PjBL enhances students' problem-solving skills, collaboration, and creativity. As noted by Suryanti et al. (2020), the application of AR in technology-based projects significantly increases student participation and learning outcomes. Thus, this technology not only aids students in understanding theoretical concepts but also facilitates the application of knowledge in real-world situations through the projects they undertake.

Learning digital electronics is a crucial component of vocational education in electrical engineering.

According to Pipattanasuk et al. (2020), and Suryanti et al. (2020), students studying digital electronics require a deep understanding of technical concepts such as electrical circuits, digital logic, and hardware. However, conventional classroom learning often fails to meet these needs due to the limitations of visual aids. Research by Dayagdag et al. (2019) revealed that students frequently struggle to grasp abstract concepts without concrete visualization. This highlights an urgent need to develop educational technologies capable of providing stronger visual representations.

Based on previous research, the learning needs in digital electronics can be categorized into three main areas: theoretical skills, practical skills, and the development of critical thinking skills. Agrawal et al. (2020), and Pipattanasuk et al. (2020) argue that students not only require conceptual understanding but also the ability to apply their knowledge in practical situations. Belani et al. (2020), Hasanah et al. (2023), Suryanti et al. (2020) further emphasize that students often need learning aids to help them understand the connection between theory and practice. This underscores the importance of developing Augmented Reality (AR) technology to assist students in visualizing and comprehending complex technical concepts.

Augmented Reality (AR) is a technology that integrates virtual elements into the real world, providing a more interactive and immersive learning experience. According to Aldalalah et al. (2019), Câmara Olim et al. (2024), AR offers a unique ability to directly visualize abstract concepts, which is particularly crucial in technical education fields such as digital electronics. Evangelista et al. (2022), and Lester et al. (2020) found that the application of AR in technical education helps students grasp concepts more quickly, as it allows them to directly observe simulations of electronic devices being studied.

Research by Darwish et al. (2023) indicates that AR design in learning can be categorized into three components: interactive simulation, dynamic visualization, and integration with problem-based projects. Noviansyah et al. (2020) emphasize the importance of AR in project-based learning, as this technology enables students to develop real-world projects in simulation environments that closely resemble actual conditions. In the context of digital electronics, a well-designed AR platform should allow students not only to understand theoretical concepts but also to apply those theories in project development.

The Project-Based Learning (PjBL) model has long been recognized as an effective method for enhancing critical and creative thinking skills (Wafiyah et al., 2025). Castaldi et al. (2019), Noviansyah et al. (2020), Suryanti et al. (2020), and Waskita et al. (2023) assert that PjBL encourages students to learn independently by

developing real-world projects that require the application of technical skills. In the context of digital electronics education, Castaldi et al. (2019), Singh et al. (2024) emphasize that PjBL enables students to integrate theory with practice, creating a learning environment more aligned with industry demands.

Research indicates that PjBL supported by AR technology can significantly improve learning outcomes. Castaldi et al. (2019) classify the application of PjBL with AR into three categories: implementation in hardware simulation, application in circuit design, and application in error analysis. (Singh & Ahmad, 2024) add that the combination of PjBL and AR not only aids students in understanding technical concepts but also provides them with practical experience in completing projects.

Overall, the existing literature highlights the significant potential of using AR in digital electronics learning through the PjBL model to enhance students' understanding of complex concepts. Aldalalah et al. (2019), and Câmara Olim et al. (2024) both found that AR aids in visualizing abstract concepts, while Evangelista et al. (2022), Zhou et al. (2020) emphasized that PjBL fosters critical and practical thinking skills. The combination of these two approaches—AR and PjBL—offers a more comprehensive and industry-relevant learning strategy.

Based on interviews with Digital Electronics teachers, several key points were identified regarding the learning process, challenges faced, and expectations for the development of technology-based learning media. Schools have implemented the Kurikulum Merdeka, which emphasizes flexibility and the development of critical and creative thinking skills through various learning activities. In the teaching process, technologies such as PowerPoint, Canva, and Eagle software have been utilized to aid in material delivery and circuit design. However, Digital Electronics learning still relies heavily on conventional resources, such as printed textbooks and teacher notes, without specialized modules tailored to support this subject.

Although the learning process proceeds as planned, students often struggle to grasp the material when it is taught solely in theory. A lack of practical tools, such as breadboards and digital trainers, poses significant barriers to understanding digital circuit and logic concepts. The teachers employ Project-Based Learning (PjBL), which effectively bridges theory and practice. However, to enhance students' understanding of abstract concepts, the teachers are interested in implementing Augmented Reality (AR)-based learning media. AR offers the potential for more interactive and engaging concept visualization. The development of AR-based media is expected to enrich students' learning experiences and better prepare them to face challenges in the technology industry.

This study hypothesizes that the application of AR in digital electronics learning using the PjBL model enhances students' understanding of complex material and fosters their active engagement in project-based learning activities. Given the growing demand for interactive and technology-driven learning environments in the era of Kurikulum Merdeka, there is an urgent need to develop innovative instructional media that can support conceptual visualization and practical skill development. Therefore, this study focuses on the development of an Augmented Reality (AR)-based learning medium integrated with the Project-Based Learning (PjBL) model, specifically designed to support the teaching of digital electronics. By addressing both the theoretical and practical needs of vocational students, the research aims to provide an instructional solution aligned with 21st-century education goals and the demands of Industry 4.0.

Method

This study was conducted by analyzing the needs of teachers at SMK Negeri 2 Depok in Yogyakarta. The research employed a Research and Development (R&D) approach, a method designed to produce products within specific professional fields, followed by derivative products, and to assess the effectiveness of these products (Hendri et al., 2021).

The development design utilized in this study was the ADDIE model, which consists of five stages: Analysis, Design, Development or Production, Implementation or Delivery, and Evaluation. This model was chosen because ADDIE is a widely used instructional design framework that is suitable for developmental research (Ganefri et al., 2020).

The first stage of this developmental research is the analysis stage. In this needs analysis, several activities are conducted, including: analyzing existing problems, setting objectives, student analysis, analysis of available resources, and material analysis.

In the stage of analyzing existing problems, the researcher aims to identify the challenges faced in schools. This stage is designed to uncover and identify issues related to the learning process. It is carried out through preliminary observations conducted via interviews with the Head of the Electronics Engineering Program and subject teachers of Electronics Engineering. This ensures that the Augmented Reality-based learning media designed in the future can address the problems encountered in schools and by educators during the teaching and learning process.

The next step is to establish the objectives for designing the AR-based Digital Electronics learning

media. The AR learning media for Digital Electronics is designed to align with the learning objectives that students are expected to achieve, ensuring consistency with the Learning Outcomes (LO). The LO refers to the competencies that students must attain at each phase of learning. These Learning Outcomes are designed to guide the intracurricular learning process and serve as the primary reference for lesson planning, without requiring additional reference to the Content Standards document.

In addition, this analysis aims to identify the resources needed for development. It is also used to determine whether the school selected as the research subject is willing to support the research process and to identify human resources that will contribute to the development of AR-based Digital Electronics learning media using the ADDIE model.

The final stage is Material Analysis. In this stage, the researcher will review the curriculum implemented in the school and analyze the Learning Outcomes (LO) that serve as a reference for product development.

Result and Discussion

Based on interviews conducted with Electronics Engineering teachers regarding the needs in the Digital Electronics learning process, it was identified that developing Augmented Reality (AR)-based learning media is crucial to support a more effective learning process. The results of the interviews are summarized in Table 1.

Table 1. Needs Analysis Based on Responses from Electronics Engineering Teachers

Question	Answer
What curriculum is used in the school?	Merdeka Curriculum
How is the use of technology such as smartphones or computers applied in learning activities?	Technology has been utilized in classroom learning, including using presentation tools like PowerPoint and Canva. Students are also encouraged to use smartphones to support Digital Technology learning, such as searching for resistor values, and to use computers for designing electronic circuits with the help of Eagle software.
What teaching materials are used during Digital Electronics learning?	Printed books and simple additional materials from teacher notes.
Is a specific module used in Digital Electronics learning? If so, specify its type.	Modules are not used because no specific module for Digital Electronics is available. In this case, teaching relies on notes written on the blackboard.
How is the learning process of Digital Electronics in class? Is it going well?	The learning process of Digital Electronics is going quite well and aligns with the planned semester learning program. Digital electronics is part of the "Concepts of Electricity and Electronics" subject, which is covered in Phase E. Students are expected to understand the basic workings of systems like Boolean algebra, Boolean logic, basic electrical techniques, analog and digital electronics, basic applications of electronics circuits, and optical electronics.
Is the material of Digital Electronics difficult for students to understand if taught only in theory?	Yes, students often find it challenging because they need hands-on practice to understand digital circuits and electronic logic.
What difficulties do students face when learning Digital Electronics?	Difficulties arise due to a lack of prior knowledge about Digital Electronics. Students need to be meticulous in arranging circuits. The lack of hands-on practice, limited tools, and time constraints hinder their development of practical skills. Students struggle with digital logic understanding without visual media and face challenges in using breadboards or tools for digital trainers.
How do students respond to Digital Electronics learning?	Students respond enthusiastically and enjoy completing practical tasks until finished. However, they remain curious about what Digital Electronics entails in real-world conditions, as much of the material taught is theoretical.
What methods are used in the Digital Electronics learning process?	Project-Based Learning (PjBL). In this method, students are involved in projects that require them to develop digital logic concepts and circuits based on real-life contexts. For example, they are tasked with designing simple circuits using hardware.
Have you ever heard about media-based Augmented Reality?	It has not been used before, but there is interest in learning about it and implementing it in teaching.
Do you agree with developing AR-based teaching media?	Strongly agree because AR can help visualize digital circuits more interactively and attractively.
What Digital Electronics material is most suitable for AR?	Basic logic gates (AND, OR, NOT) and combination circuits like encoders and decoders.
What are your expectations for the development of AR-based teaching media for Digital Electronics?	A significant expectation is that students will more easily understand abstract concepts through interactive and realistic visualizations.

As a result, students are encouraged to become more independent in their learning, necessitating the development of modules as a learning companion. The Independent Curriculum aims to offer flexibility in learning and adapt materials to the needs of students. Additionally, the curriculum prioritizes the development of critical and creative thinking skills through various learning activities (Pamorti et al., 2024; Prananta et al., 2024).

Technology has been utilized in the teaching of Digital Electronics. Teachers use presentation tools such as PowerPoint and Canva to aid in delivering material. Additionally, students are encouraged to leverage smartphones for accessing supplementary information, such as resistor values, and to utilize software like Eagle for designing electronic circuits (Angga Rini & Selfi Cholifah, 2020).

Digital Electronics learning still relies heavily on conventional teaching materials, such as printed textbooks and additional notes provided by teachers. There is no specific module designed to support Digital Electronics learning, leaving students dependent on notes written by teachers on the board.

The learning process runs relatively well in accordance with the lesson plan. In the Independent Curriculum (Kurikulum Merdeka), Digital Electronics is part of Phase E, where students study topics such as number systems, Boolean algebra, basic electrical techniques, and the applications of analog and digital electronics.

Students often struggle to understand Digital Electronics material when it is taught only theoretically. They require hands-on practice to grasp the concepts of digital circuits and electronic logic. However, the limited availability of practical tools, such as breadboards and digital trainers, poses a significant obstacle.

Students demonstrate high enthusiasm when working on practical assignments. However, they express curiosity about real-world applications of Digital Electronics outside the classroom, highlighting the need for reinforcement through realistic simulations.

Teachers employ the Project-Based Learning (PjBL) method, where students are assigned projects such as designing logic circuits or creating simple circuits using hardware. This method is considered effective in bridging the gap between theory and practice.

Teachers have not yet utilized AR-based learning media but are interested in implementing it due to AR's potential to assist in visualizing abstract concepts in a more interactive and engaging manner. Teachers believe that AR could help students understand materials such as basic logic gates (AND, OR, NOT) and combinational circuits like encoders and decoders.

Teachers hope that the development of AR-based media can assist students in understanding abstract concepts through realistic and interactive visualizations, thereby enhancing the overall learning experience. This aligns with efforts to improve students' competencies in facing the challenges of the technology industry.

Conclusion

This study aims to analyze the needs of teachers and students in Digital Electronics learning and to design Augmented Reality (AR)-based learning media using the Project-Based Learning (PjBL) model. Based on the needs analysis, it was found that students require more interactive learning media to support the visualization of abstract concepts such as logic gates, encoders, and decoders. Additionally, teachers expect learning media that can facilitate students in gaining a deeper understanding of concepts through real-world project-based approaches. The results of this study show that AR technology has significant potential to enhance students' understanding of Digital Electronics materials, especially through integration into the PjBL model. By leveraging AR, students can interact directly with digital circuit simulations, thereby improving their practical skills, critical thinking, and collaboration abilities. The developed product is expected to serve as a reference for further development processes in creating innovative learning media that meet the demands of the digital era and industry needs. Based on the needs analysis, it can be concluded that the development of AR-based learning media for Digital Electronics subjects using the Project-Based Learning (PjBL) model is highly relevant and necessary. This media will help students understand abstract concepts through interactive visualizations, enhance learning interest, and provide in-depth practical experiences without the need for physical tools.

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Conceptualization, Hartati and Putu Sudira; methodology, Hartati; software, Dedi Setiawan; validation, Hartati, Putu Sudira, and Dedi Setiawan; formal analysis, Hartati; investigation, Hartati; resources, Hartati; data curation, Hartati; writing—original draft preparation, Hartati; writing—review and editing, Dedi Setiawan and Putu Sudira; visualization, Dedi Setiawan; supervision, Putu Sudira; project administration, Hartati; funding acquisition, Hartati. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare that there is no conflict of interest related to the publication of this work.

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