



Development of Augmented Reality-Assisted Learning Materials on the Coordination System to Enhance Systems Thinking Skills

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Abstract: This study aimed to develop Augmented Reality-assisted instructional materials on the coordination system, to describe their practicality in improving students' systems thinking skills, and to evaluate the effectiveness of the developed instructional materials. The research employed a Research and Development (R&D) approach based on the 4-D development model, which consists of four stages: define, design, develop, and disseminate. The instruments used included a needs analysis questionnaire, validity questionnaire, practicality questionnaire, learning implementation observation sheet, and a systems thinking skills pretest-posttest. The results showed that the instructional materials were highly valid, with content validity of 89.5%, construct validity of 94.8%, and attractiveness validity of 97.2%. The Augmented Reality-assisted instructional materials were practical for improving systems thinking skills, as indicated by the implementation of learning activities, which reached 92.5%. Product evaluation responses revealed that most students provided highly positive assessments, with a percentage of 97.22%, while teachers' assessments reached 95.7%. Furthermore, the instructional materials were effective in enhancing systems thinking skills, as demonstrated by a high N-Gain score of 0.79 and a large effect size of 1.95. Based on these findings, the developed Augmented Reality-assisted instructional materials were effective in improving students' systems thinking skills.

Keywords: Augmented reality; Learning materials; Systems thinking skills

Introduction

One of the key characteristics of the Merdeka Curriculum is the flexibility it provides for teachers to develop meaningful learning experiences through project-based and contextual approaches (Anwar et al., 2025). Such approaches offer significant opportunities to foster systems thinking skills, as students are encouraged to view phenomena holistically rather than understanding isolated fragments of knowledge (Hamijaya et al., 2023). Systems thinking is a holistic approach that analyzes phenomena as interconnected components within a larger system, where each component interacts with and influences one another (Utami et al., 2022; York et al., 2019). Systems thinking

skills are increasingly essential because many real-world problems are complex, multifaceted, and cannot be effectively addressed through natural science perspectives or conventional approaches alone (Haniyah et al., 2022).

Systems thinking is an essential skill for students, as it enables them to connect concepts across different topics more effectively. This skill contributes to the development of students' understanding of dynamic living systems (Schuler et al., 2018). Systems thinking is particularly important in education because learning in schools often remains focused on isolated facts rather than on systemic relationships and processes that evolve over time. Consequently, fostering systems thinking skills can help students develop a more comprehensive

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understanding of complex phenomena and the interconnections among their components.

Although systems thinking has been recognized as an important educational goal, its integration into educational practice remains limited (Gilissen et al., 2020). This can be observed in classroom learning, where instructional practices continue to focus primarily on the acquisition of fragmented knowledge and the achievement of academic scores rather than on developing a holistic understanding of interconnected concepts (Agustina et al., 2023). Furthermore, science education often emphasizes cognitive aspects alone, with insufficient attention given to solving real-life problems and fostering the skills and attitudes required to understand complex systems (Weinert, 2001). A study conducted by Nuraeni et al. (2020) revealed that both teachers and students rarely connect learning materials with related concepts from other topics, making it difficult for students to identify relationships among concepts when completing systems thinking assessments. As a result, students' systems thinking skills were found to be at a low level.

Based on a preliminary online survey conducted through Google Forms involving 40 science teachers from three regencies Tanggamus, Pringsewu, and Pesawaran it was found that 70% of the teachers were familiar with the concept of systems thinking. However, familiarity with the concept was not accompanied by sufficient understanding of its implementation, as 75.8% of the respondents reported that they did not understand how to apply systems thinking in the learning process. In addition, 65% of the teachers still considered systems thinking skills to be of limited importance for students, and 72.5% had not yet integrated instructional materials that encourage students to engage in systems thinking.

Raved et al. (2014) reported that students' low systems thinking skills are influenced by their tendency to solve problems using only a single solution strategy without considering or generating alternative approaches. In fact, the development of systems thinking in science education requires students to connect one concept with other related concepts in order to understand the relationships within a system (Kartini et al., 2019; Roehl et al., 2013). Systems thinking skills are closely associated with domain-specific knowledge; however, this knowledge must possess systemic characteristics that enable learners to recognize interactions, interdependencies, and relationships among components within a system (Orgill et al., 2019).

This is consistent with the Phase D Science Learning Outcomes in the Merdeka Curriculum, which emphasize understanding the relationships between the structures and functions of organs and organ systems in living organisms, including the coordination system

(nervous system, sensory organs, and endocrine system) (Kemendikbudristek, 2022). Through these learning outcomes, students are expected to analyze the interactions among organ systems and explain how the body functions as an integrated whole (Jayanti et al., 2023). Therefore, the coordination system serves not only as a body of scientific knowledge but also as a strategic context for fostering systems thinking skills, as students are encouraged to understand how changes in one component can influence the overall functioning of the body (Andini et al., 2024).

The teaching of the coordination system generally addresses the nervous system, sensory organs, and endocrine system as separate topics without emphasizing the interrelationships and interactions among them (Fahrnunisa et al., 2023). Consistent with the findings of the preliminary study, 55% of science teachers reported that they had not integrated connections among concepts when teaching the coordination system. In fact, the human coordination system functions as an integrated system in which multiple components work together to regulate and maintain bodily functions. The coordination system represents a complex system characterized by dynamic interactions among its components to achieve harmonious functioning within the human body (Jayanti et al., 2023).

The results of the preliminary study involving students revealed that 82% of them experienced difficulties in understanding abstract concepts, particularly those related to the coordination system. These difficulties arise because the topic requires students to visualize the structures and functions of organs that operate in an integrated manner, while the instructional media commonly used by teachers are still limited to verbal explanations and two-dimensional images. Furthermore, 82% of the students reported that their teachers rarely utilized three-dimensional (3D) visual media during the learning process, resulting in a less optimal understanding of the interrelationships among organs within the coordination system. These findings indicate the need for innovative instructional media that can help students visualize abstract concepts in a more concrete, interactive, and contextual manner.

These challenges can be addressed through the use of Augmented Reality (AR) technology, as AR is capable of presenting interactive three-dimensional representations that enable students to visualize the organs involved in the coordination system, such as the brain, nerves, sensory organs, and endocrine system. Through 3D models that can be rotated, enlarged, and examined in detail, students can gain a more concrete understanding of complex biological structures and processes (Fajriyyah et al., 2024). Consistent with this, Fajriani et al. (2021) reported that the use of Augmented

Reality in learning the endocrine system facilitated students' conceptual representation shifts toward a more complex and integrated understanding. Furthermore, Sholikha et al. (2024) demonstrated that Augmented Reality-based learning media integrated with the Problem-Based Learning (PBL) model on virus-related topics not only enhanced students' understanding of abstract concepts but also made learning more engaging and meaningful.

Unlike previous studies, the novelty of the Augmented Reality (AR) application developed in this study lies not only in its ability to visualize the organs involved in the coordination system but also in its capacity to present the functions of each organ interactively through three-dimensional (3D) models. In addition, the developed AR features are designed to visualize cause-and-effect relationships within the coordination system based on the hierarchy of systems thinking, thereby helping students develop a more comprehensive understanding of the interconnections among system components.

The AR-assisted instructional materials on the coordination system are integrated with the Discovery Learning model, which emphasizes students' active involvement in discovering and constructing knowledge independently. To further support the development of systems thinking skills, the instructional materials are complemented by Student Worksheets (LKPD) designed according to the systems thinking hierarchy proposed by Keynan et al. (2014).

Another innovative aspect of this development is its accessibility. Students are not required to install a dedicated application on their devices; instead, they can access the AR features simply through an internet connection and by scanning the provided QR codes. This ease of access supports the implementation of more inclusive and flexible learning experiences and aligns with the principles of the Merdeka Curriculum, which encourages the integration of digital technologies to enrich students' learning experiences. Therefore, there is a need for Augmented Reality-assisted instructional materials specifically designed to foster students' systems thinking skills.

Method

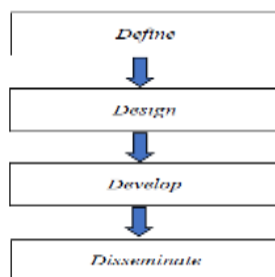


Figure 1. 4D development model design

This research is Research and Development (R&D). The research design used is the 4D (four-D) development model, which consists of define, design, develop, and disseminate (Thiagarajan et al., 1974). The 4D model can be presented in Figure 1. The research procedure employed in this study is illustrated in Figure 2.

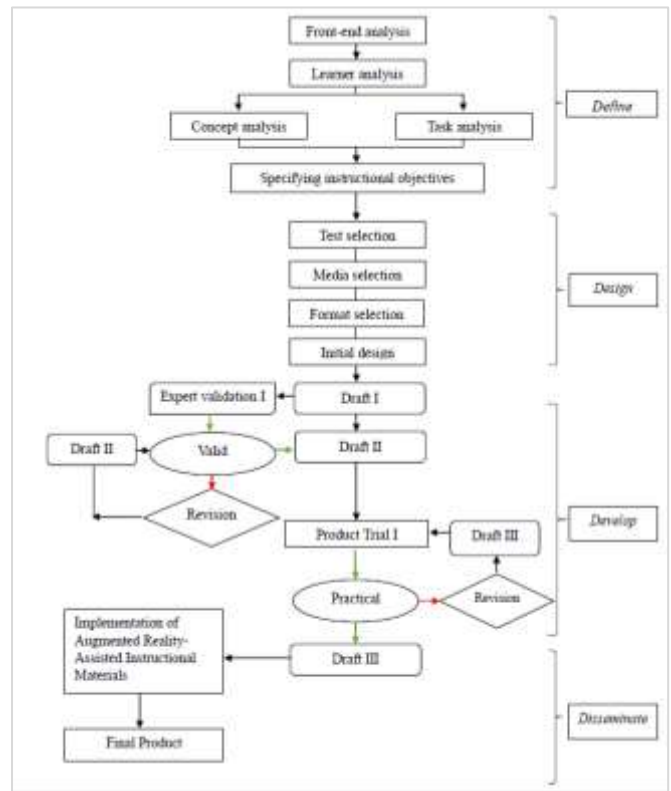


Figure 2. Research flowchart

The development research was conducted using the 4D model, consisting of the following stages:

Define

The define stage was carried out to identify and determine the needs for developing augmented reality-assisted learning tools. This stage involved analyzing learning problems, student characteristics, curriculum requirements, and the learning environment to ensure that the developed product met the needs of both teachers and students.

Design

The design stage aimed to produce the first draft of the augmented reality-assisted learning tools. The learning tools were designed based on students' characteristics, learning needs, and school conditions. At this stage, lesson plans, student worksheets, assessment instruments, and augmented reality components were systematically developed.

Develop

The develop stage aimed to produce and evaluate augmented reality-assisted learning tools on the topic of the coordination system to improve students' systems thinking skills. This stage involved expert validation, product revision, and field testing to ensure that the developed learning tools met the criteria of validity, practicality, and effectiveness. Revisions were made based on feedback and recommendations provided by experts before the product was implemented in the learning process.

Disseminate

After the learning tools had been tested and refined, the dissemination stage was conducted through packaging, diffusion, and adoption activities. This stage aimed to facilitate the utilization of the developed learning tools by other science teachers. The final product was disseminated through the Science Teachers' Subject Teacher Forum (MGMP IPA) and shared with educators to support wider implementation in science learning.

Data were collected using questionnaires and systems thinking skills tests. The questionnaires included expert validation questionnaires, teacher and student response questionnaires regarding the attractiveness, suitability, and construction of the learning tools, as well as learning implementation questionnaires. In addition, pretests and posttests were administered to measure students' systems thinking skills. The data obtained from the pretest and posttest results were analyzed using the N-Gain formula.

$$N - Gain = \frac{Posttest\ Score - Pretest\ Score}{Smax - Pretest\ score} \quad (1)$$

Table 1. N-Gain Scores of Students' Systems Thinking Skills

Class	N Gain		Average N-Gain	Criteria
	Pretest	Posttest		
Experiment	40	88	High	High
Control	41	70	Medium	Medium

The feasibility score of each item was calculated using the following formula.

$$P = \frac{\sum S}{Smax} \times 100\% \quad (2)$$

Description:

- P = feasibility percentage
- ΣS = total score obtained
- Smax = maximum score

The validity data were analyzed using the following equation.

$$\bar{P} = \frac{\sum \%X_i}{Smax} \times 100\% \quad (3)$$

Description:

- P̄ = mean validity percentage
- Σ%Xi = sum of the percentages of all statement items
- N = total number of statement items

Result and Discussion

The results and discussion of the data obtained from the pretest and posttest scores of students' systems thinking skills were presented using N-Gain scores, which were calculated based on the formula and criteria proposed by Hake (1999). The N-Gain scores were calculated using Microsoft Excel 2017. Based on the calculations, the percentage distribution of N-Gain categories for each student in both the control and experimental groups was obtained, as presented in Figure 3.

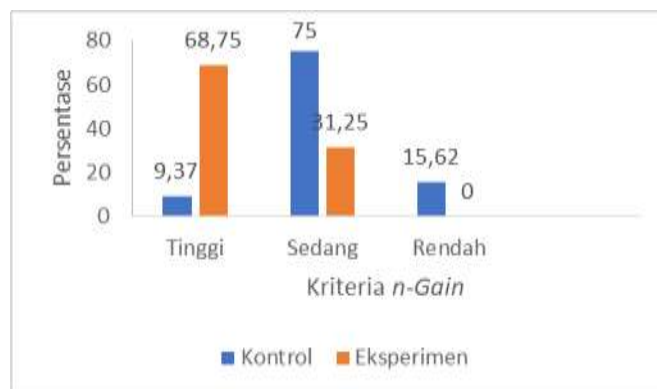


Figure 3. Percentage distribution of n-gain categories for systems thinking skills

Based on Figure 3, the distribution of N-Gain scores indicates that the experimental group achieved greater improvement in systems thinking skills than the control group. A total of 68.75% of students in the experimental group were categorized as having a high N-Gain, whereas only 9.37% of students in the control group fell into this category. Furthermore, no students in the experimental group were classified in the low category, while 15.62% of students in the control group remained in this category. These findings suggest that the use of Augmented Reality-assisted learning media was more effective in improving students' systems thinking skills than conventional instruction. Three-dimensional visualization enabled students to better understand the relationships among components within the coordination system, thereby facilitating knowledge construction and enhancing their systems thinking skills.

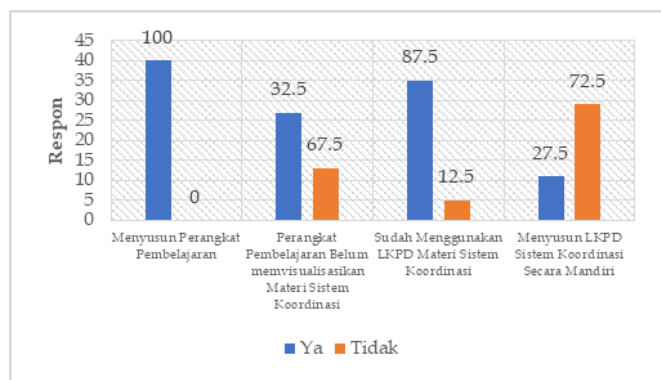


Figure 4. Teachers' responses to the learning tools

Based on the graph, it was found that 100% of teachers had developed learning tools for classroom instruction. However, 32.5% of teachers reported that the learning tools they developed did not include visualizations of the learning content, particularly for the coordination system topic. In addition, 87.5% of teachers had used student worksheets (LKPD) in teaching the coordination system, but 72.5% indicated that the worksheets were not self-developed and were instead obtained from online sources. This finding suggests that most teachers do not independently develop student worksheets, resulting in learning materials that lack visual representations and technological features that could support the teaching of the coordination system. These findings are illustrated in Figure 5.

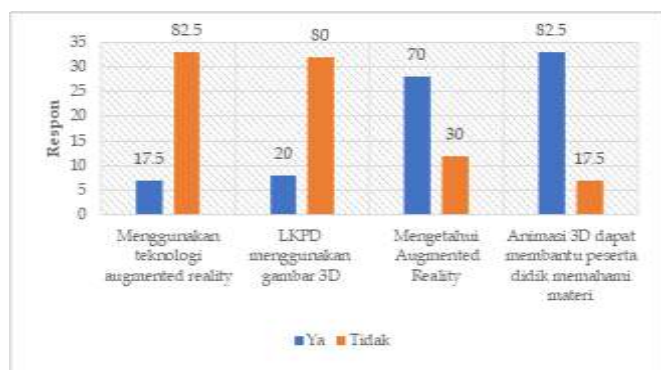


Figure 5. Teachers' responses regarding student worksheets (LKPD) and the use of augmented reality

Based on Figure 5, the majority of teachers (82.5%) had not yet implemented augmented reality technology in their teaching practices, although 70% were familiar with the technology. In addition, the use of student worksheets (LKPD) incorporating 3D images remained relatively low, with only 20% of teachers reporting such use. These findings indicate that the integration of innovative digital technologies in learning has not been fully optimized. Nevertheless, 82.5% of teachers agreed that 3D animations could help students better understand learning materials. This finding highlights

the need for the development of augmented reality-based learning materials that integrate three-dimensional visualizations into the learning process to enhance students' conceptual understanding. This need is further supported by teachers' responses regarding the importance of systems thinking skills, as shown in Figure 6, where most teachers indicated that students require learning media capable of presenting relationships among system components more clearly.

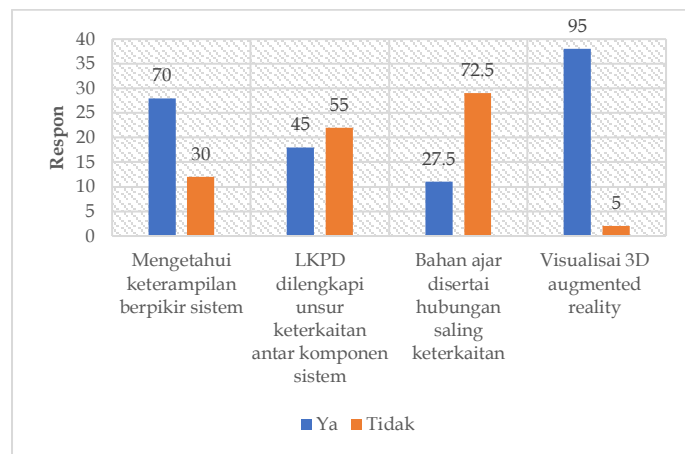


Figure 6. Teachers' responses regarding systems thinking skills

The graph indicates that 70% of teachers were familiar with systems thinking skills; however, 55% of them did not integrate systems thinking elements into the student worksheets (LKPD) they developed. Furthermore, in the coordination system topic, most teachers reported that 72.5% of the worksheets did not present the interrelationships among content components, which are essential for representing systems thinking principles. In addition, 95% of teachers agreed that learning about the coordination system requires 3D visualizations to help students understand the relationships between structures and functions within the system. Therefore, the augmented reality-assisted learning tools were designed using a systems thinking approach to facilitate students in identifying and understanding the interconnections among system components through three-dimensional (3D) visualizations of the coordination system topic.

Conclusion

This development research resulted in augmented reality (AR)-assisted learning tools for the coordination system topic that were found to be valid, practical, and effective in improving students' systems thinking skills. The validation results indicated that the learning tools were highly valid in terms of content (89.5%), construction (94.8%), and attractiveness (97.2%). In

terms of practicality, the learning tools achieved an implementation rate of 92.5% and received highly positive responses from both students (97.22%) and teachers (95.7%), indicating that they were practical for classroom use. Regarding effectiveness, the AR-assisted learning tools significantly improved students' systems thinking skills. The experimental group achieved an average N-Gain score of 0.79, categorized as high, and an effect size of 1.95, categorized as large, substantially outperforming the control group, which achieved only a moderate N-Gain category. Therefore, the AR-assisted learning tools developed using the 4-D model are effective in fostering and enhancing students' systems thinking skills, particularly in learning the coordination system at the junior high school level. Future research is recommended to implement these learning tools in a wider range of schools and educational contexts, as well as to investigate their effectiveness in improving other higher-order thinking skills.

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Author Contributions

The author's contribution in the field of education is to provide an overview of augmented reality-assisted learning tools that can visualize abstract material and aim to improve students' systematic thinking skills, particularly in coordination system material.

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Conflicts of Interest

No conflict of interest.

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