Development of an AR-Based Interactive Solar System Educational Tool (APEKIB) to Enhance Critical Thinking Skills in Elementary School Students

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Abstract

This study aimed to develop APEKIB, an interactive Solar System learning medium integrating a physical teaching aid with digital learning resources, including augmented reality (AR), and to examine changes in students' test performance following its classroom use. The study employed a research-and-development approach using the ADDIE model, consisting of Analysis, Design, Development, Implementation, and Evaluation. The participants were 23 sixth-grade students at SD Madani Cilegon, Indonesia. Data were collected through needs interviews, observation, documentation, product validation, and pretest and posttest assessments. APEKIB combines an infraboard display, planet models made from reused balls, orbit paths, and QR-code access to three-dimensional Solar System visualisations through Assemblr Edu, instructional videos, a poster, and learning exercises. Assessment using one combined validation form covering content suitability, media and visual design, learning interactivity, and support for critical thinking yielded 88 out of 110 possible points (80%). The mean student score increased from 61.86 on the pretest to 89.20 on the posttest. The normalized gain (N-gain) was 0.72, classified as high. Individually, 16 students (69.57%) achieved a high N-gain and seven students (30.43%) achieved a moderate N-gain. These findings indicate improved test performance following APEKIB-supported learning in the group studied. However, because the evaluation involved a single group without a comparison group, the improvement cannot be attributed solely to the learning medium.

Keywords: *APEKIB, Augmented Reality, Critical Thinking, Elementary Education, Solar System.*

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A. INTRODUCTION

Science learning in elementary schools should provide students with opportunities to understand concepts through observation, information processing, and reasoning. Learning should not be limited to memorising facts but should also encourage students to investigate phenomena, connect information, and develop explanations based on evidence. These learning experiences are particularly important when students study scientific concepts that are difficult to observe directly.

The Solar System is one of the topics that presents challenges for elementary school students. The planets and other celestial bodies are located at considerable distances from Earth, and their movement and arrangement cannot be observed directly in everyday classroom activities. Students may therefore experience difficulties in developing accurate mental representations of the characteristics,

positions, and relationships among celestial bodies. The use of concrete models and digital visualisations can provide alternative representations to help students understand these abstract concepts.

Learning media play an important role in supporting the delivery of instructional content and creating meaningful learning experiences. One technology that offers opportunities for visual and interactive learning is Augmented Reality (AR). AR enables digital objects to be displayed in a real-world environment through digital devices. In educational settings, this technology can enrich students' learning experiences by providing visual representations and opportunities to interact with learning objects. Previous studies have identified the potential benefits of AR in education, while also highlighting challenges related to pedagogical suitability, technological resources, and teacher guidance (Azuma, 1997; Bacca et al., 2014; Akçayır & Akçayır, 2017).

Nevertheless, the use of technology in learning should be connected to clearly defined instructional objectives. Digital visualisation alone does not automatically develop students' higher-order thinking skills. Students need structured learning activities that encourage them to interpret information, analyse relationships, evaluate statements, draw conclusions, and explain their reasoning. These activities are essential components of critical thinking.

Critical thinking is an important ability for elementary students because it helps them process information, examine evidence, and make reasoned decisions. In science learning, students can practise critical thinking by comparing the characteristics of planets, identifying relevant information, evaluating statements about celestial bodies, and explaining conclusions based on observations. Therefore, learning media should not only present information but should also provide opportunities for students to engage in meaningful thinking activities.

Based on these considerations, this study developed APEKIB Interactive Solar System, a learning medium that integrates a physical teaching aid with digital learning resources. The physical component consists of an infraboard display and planet models made from reused balls. The digital component can be accessed through barcodes or QR codes that connect students to three-dimensional Solar System visualisations through Assemblr Edu, instructional videos, a Solar System poster, and learning exercises. In this design, the QR code serves as an access mechanism, while AR represents one of the digital learning resources accessed through the code.

The integration of physical and digital components is expected to provide students with opportunities to observe, explore, compare, and discuss Solar System concepts through different representations. The teacher also guides students in connecting the information obtained from the learning resources with questions that require interpretation and reasoning.

Accordingly, this study had three objectives: (1) to develop APEKIB Interactive Solar System as an AR-supported learning medium using the ADDIE model; (2) to describe the product assessment results based on the validation

instrument used; and (3) to examine changes in students' test performance before and after using the medium. The study contributes to the development of integrated physical and digital learning media for Solar System instruction in elementary schools.

B. METHOD

This study employed a Research and Development (R&D) approach using the ADDIE instructional design model. The ADDIE model consists of five stages: Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). This model was selected because it provides a systematic procedure for identifying learning needs, designing instructional products, developing the products, implementing them in the classroom, and evaluating the results.

The research was conducted at SD Madani, Cilegon, Banten, Indonesia, from February to May 2026. The participants were 23 sixth-grade students. The participants were selected purposively based on their involvement in Grade VI science and social studies (IPAS) learning and the classroom trial of the developed medium.

The development process followed the five stages of the ADDIE model.

a. Analysis

The Analysis stage focused on identifying students' learning needs, the characteristics of the Solar System topic, and the need for concrete and interactive learning media. The analysis considered the abstract characteristics of Solar System concepts and the importance of providing visual representations that could support students' understanding and reasoning.

b. Design

The Design stage involved planning the physical and digital components of APEKIB. The physical design included an infraboard display, planet models made from reused balls, orbit paths, and storage for the planet components. The digital design included QR codes, three-dimensional Solar System visualisations, instructional videos, a learning poster, and exercises.

The learning activities were also designed to encourage students to interpret information, analyse relationships, evaluate statements, draw inferences, and explain their answers.

c. Development

At this stage, the product was constructed based on the design. The physical medium was made using an infraboard board and planet models of different sizes and colours. The digital resources were connected to the physical medium through QR codes. These resources included three-dimensional Solar System visualisations accessed through Assemblr Edu, instructional videos hosted on YouTube, a Solar System poster, and online exercises prepared using Canva. Written exercises were also provided as part of the learning activities.

d. Implementation

The developed medium was implemented in Grade VI learning activities at SD Madani Cilegon. Students began by observing the physical display and planet models. They then scanned the QR codes to access digital learning resources, explored the visualisations, watched instructional videos, and observed the learning poster. The activities continued with exercises related to the Solar System.

During the learning process, the teacher guided students in connecting information from the physical and digital representations. Students were encouraged to compare information, respond to questions, and explain the reasons for their answers.

e. Evaluation

The Evaluation stage involved reviewing the product assessment, classroom implementation, and student test results. The evaluation was used to identify aspects of the product that required improvement and to examine changes in student performance after the learning activities.

Data were collected through needs interviews, observation, documentation, product validation, and pretest and posttest assessments. The product assessment used one combined validation form consisting of 22 items rated on a five-point scale, with a maximum possible score of 110. The instrument covered four aspects: content suitability, media and visual design, learning interactivity, and support for critical thinking. The learning exercises were designed around five critical-thinking indicators: interpretation, analysis, evaluation, inference, and explanation or reasoning. The pretest and posttest were administered to examine changes in students' test performance before and after the use of APEKIB.

The validation data were analysed descriptively by comparing the score obtained with the maximum possible score. The percentage was calculated using the following formula:

$$\text{Validation Percentage} = \frac{\text{Obtained Score}}{\text{Maximum Score}} x\ 100\%$$

Student test results were analysed by comparing the mean pretest and posttest scores. Normalized gain (N-gain) was used to describe the improvement in student test performance. The N-gain results were interpreted using the categories reported in the research records. Observation and interview data were described qualitatively to provide information about the development and classroom implementation of the medium.

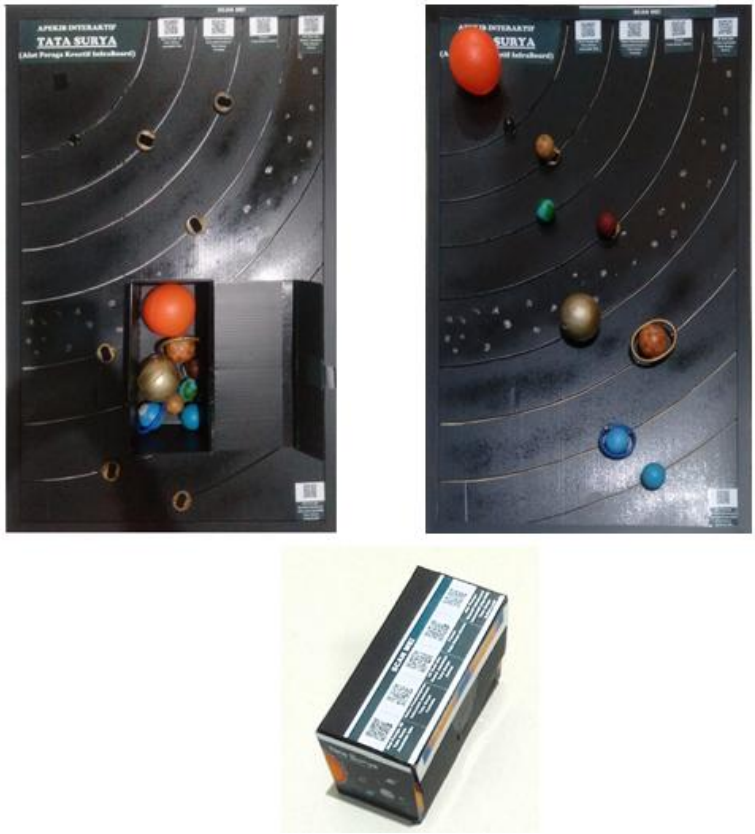


Figure 1. Physical teaching aid equipped with QR Code Access ti digital learning resources

The digital component is accessed through QR codes placed on the learning medium. One of the codes directs students to a three-dimensional Solar System visualisation through Assemblr Edu. Other codes provide access to instructional videos, a Solar System poster, and learning exercises. The exercises are available in written and online formats.

The use of QR codes connects the physical teaching aid with the digital resources. Consequently, students can move from observing physical models to exploring digital visualisations and completing learning exercises. This sequence provides opportunities to obtain information through different representations and use that information to respond to learning questions.

The teacher plays an important role in guiding students throughout these activities. Students are encouraged not only to observe the models and digital visualisations but also to compare planetary characteristics, identify relevant information, and explain their answers. Thus, the learning value of APEKIB depends on the integration of the medium with purposeful classroom activities.

C. RESULTS AND DISCUSSION

1. Product Validation Results

The product assessment was conducted using one combined validation form covering four assessment aspects. The results are presented in Table 1.

Table 1. Product Assessment Results Based on the Combined Validation Form

Assessment aspect	Number of items	Score	Percentage
Content suitability	5	19/25	76.00%
Media and visual design	7	27/35	77.14%
Learning interactivity	5	22/25	88.00%
Support for critical thinking	5	20/25	80.00%
Overall	**22**	**88/110**	**80.00%**

The combined validation form yielded a score of 88 out of 110, equivalent to 80%. Among the four assessment aspects, learning interactivity received the highest percentage (88%), while content suitability received 76%. Media and visual design obtained 77.14%, and support for critical thinking obtained 80%.

These results describe the assessment recorded in the validation instrument. The relatively high score for learning interactivity indicates that this aspect received a stronger assessment than the other aspects in the form. Meanwhile, the content suitability aspect received the lowest percentage and may therefore be considered in further product refinement.

It is important to note that the available research record reports one combined validation form. Therefore, the results should not be interpreted as separate validation outcomes from different expert panels. The 80% score represents the overall result of the instrument used in this study.

2. Changes in Students' Test Performance

The students' test results showed an increase in the mean score after the implementation of APEKIB. The mean pretest score was 61.86, while the mean posttest score reached 89.20. The class N-gain was 0.72, which was classified as high.

At the individual level, 16 students (69.57%) achieved a high N-gain, while seven students (30.43%) achieved a moderate N-gain. No students were reported in the low N-gain category.

Table 2. Summary of Students' Test Performance

Measurement	Result
Mean pretest score	61.86
Mean posttest score	89.20
Class N-gain	0.72
High N-gain category	16 students (69.57%)
Moderate N-gain category	7 students (30.43%)
Low N-gain category	0 students

The difference between the pretest and posttest means indicates improved test performance after the use of APEKIB in the group studied. The learning activities combined physical observation, digital visualisation, instructional videos, and exercises. These components provided students with different ways to access information about the Solar System.

The physical models allowed students to observe a concrete representation of the planets and their arrangement. Meanwhile, the three-dimensional visualisations provided additional visual information that could be explored through digital devices. The instructional videos and poster offered further learning resources, while the exercises encouraged students to use the information they had obtained.

Although the findings indicate an increase in student test performance, the results should be interpreted carefully. The study used a single-group pretest–posttest design without a comparison group. Therefore, the increase cannot be attributed solely to the use of APEKIB. Other factors, such as classroom instruction, students' prior knowledge, and learning experiences during the implementation, may also have contributed to the observed changes.

3. APEKIB and Critical-Thinking Activities

APEKIB was designed to support learning activities related to five critical-thinking indicators: interpretation, analysis, evaluation, inference, and explanation or reasoning. These indicators were reflected in the learning exercises and the teacher-guided activities. Interpretation involves identifying and understanding information presented through the physical models, digital visualisations, videos, and posters. Analysis involves examining relationships among the planets and identifying similarities or differences in their characteristics. Evaluation requires students to assess statements or information about the Solar System. Inference involves drawing conclusions based on the information obtained, while explanation or reasoning requires students to communicate the reasons supporting their answers.

The integration of physical and digital learning resources provides opportunities for students to examine information from different representations. For example, students can observe the planet models, explore three-dimensional visualisations, and compare the information obtained with the instructional materials. The teacher can then provide questions that require students to explain relationships and justify their conclusions.

However, the availability of interactive media does not automatically develop critical thinking. The quality of the questions, classroom discussion, and teacher guidance remains essential. Therefore, APEKIB should be understood as a learning resource that can support critical-thinking activities when it is integrated with appropriate instructional strategies.

Several limitations should be considered when interpreting the findings. First, the participants consisted of 23 sixth-grade students from one school. Therefore, the results cannot be generalised to all elementary school students without further investigation. Second, the evaluation used a single-group pretest–posttest design without a comparison group. As a result, the observed increase in test performance does not establish that APEKIB was the only factor responsible for the improvement. Third, the reported test results are presented as overall scores. Separate statistical analyses for each critical-thinking indicator were not reported in the available

research results. Further research should therefore examine changes in interpretation, analysis, evaluation, inference, and explanation separately. Finally, the use of digital resources requires suitable devices, internet connectivity, and teacher assistance. These factors should be considered when implementing the medium in schools with different technological facilities.

D. CONCLUSION

This study developed APEKIB Interactive Solar System using the ADDIE model. The learning medium integrates a physical infraboard display and planet models made from reused balls with digital learning resources accessed through QR codes. These resources include three-dimensional Solar System visualisations through Assemblr Edu, instructional videos, a learning poster, and exercises.

The product assessment using one combined validation form produced a score of 88 out of 110, equivalent to 80%. Learning interactivity received the highest percentage (88%), followed by support for critical thinking (80%), media and visual design (77.14%), and content suitability (76%).

The classroom implementation involving 23 sixth-grade students showed an increase in the mean test score from 61.86 on the pretest to 89.20 on the posttest. The class N-gain was 0.72, classified as high. These findings indicate improved test performance following the use of APEKIB in the group studied.

Nevertheless, the findings should be interpreted within the limitations of the research design. The single-group evaluation does not establish that the medium was the sole cause of the improvement. Further studies involving larger samples, comparison groups, and separate analyses of critical-thinking indicators are needed to provide stronger evidence regarding the contribution of APEKIB to elementary students' critical thinking.

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