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Planetaria: Augmented reality-based learning media on solar system lessons for elementary school students

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ABSTRACT

This study aimed to develop Augmented Reality (AR)-based learning media that can assist students in understanding the material on the solar system, specifically the characteristics of the planets within it. This learning media is developed in the form of cards that can be scanned using a smartphone device, with each card displaying a three-dimensional (3D) planet object along with an audio explanation. The research method was Design and Development (D&D) with the ADDIE model (Analysis, Design, Development, Implementation, Evaluation). The results of the study show that the development of the PlanetARia media was validated by system and content experts, with average percentages of 96% and 98%, respectively. The implementation of the PlanetARia media showed positive responses from students regarding visualisation, content, and ease of use. As many as 87% of the students gave very good responses to the media's visualisation, 73% rated the content aspect as very good, and 83% of the students stated that PlanetARia was easy to use. These results indicate that PlanetARia is visually appealing, content-relevant, and provides ease for students in understanding solar system material.

INTRODUCTION

Learning about the solar system and the planets is an integral part of the science curriculum in elementary school. This material is not only crucial for introducing students to basic astronomical concepts but also for developing critical thinking skills and a sense of curiosity about the universe (Sari et al., 2023). However, in reality, material about the solar system is often challenging for students to understand due to its abstract nature and its distance from their daily experiences. Planets located millions of kilometers from Earth are certainly demanding to visualise accurately without the aid of appropriate media. Students' inability to visualise these planets can lead to confusion, misconceptions, and a decline in interest and motivation to learn (Silvi, 2022; Widya & Ernawati, 2024).

According to research by Khulaifatuzzahra et al. (2024), the teaching of the solar system in elementary schools remains dominated by conventional methods, such as textbooks and verbal explanations, which are often ineffective in visually depicting three-dimensional concepts. This causes students to struggle in understanding the relationships between planets and the overall structure of the solar system. Teachers face significant challenges in creating more engaging, concrete, and easy-to-understand learning materials. In this context, innovation in teaching methods and media becomes crucial. In the modern era, where digital technology is rapidly advancing and has become an integral part of students' daily lives, the need to provide science education that is more contextual, engaging, and meaningful is increasingly urgent.

The urgency to develop more effective and engaging learning materials is further underscored by the characteristics of today's students, the digital native generation. They have grown up in an environment saturated with digital technology and have high expectations for learning experiences that are interactive, immersive, and dynamic (Fitri, 2024). Therefore, educators must leverage innovative technologies such as augmented reality (AR) in the learning process. AR technology enables the integration of digital elements with the real world, thereby creating a more vivid learning experience and allowing students to interact directly with virtual objects within a real-world context (Dendodi et al., 2024).

This is consistent with a preliminary study conducted at a public elementary school in Bogor from October to December 2023. The preliminary study involved direct classroom observations of students, interviews with classroom teachers, and a review of diagnostic assessment results for sixth-grade students. The observation results revealed that students at the elementary school were very familiar with technology, particularly smartphones, but these devices were not yet being utilised optimally in learning. Additionally, the diagnostic assessment results indicated that students had diverse learning styles, including auditory, kinaesthetic, and visual. This necessitates the development of learning materials that meet the needs of various learning styles.

Interviews with teachers revealed that one of the greatest challenges in teaching is the difficulty in explaining abstract concepts, such as the solar system. Teachers also noted that the limitations of the learning media used so far make it demanding for students to visualise abstract planets that are far removed from their daily lives. Given these findings, the development of Augmented Reality (AR)-based learning media equipped with audio narration is expected to address these challenges, particularly in visualising concepts that are challenging to explain conventionally.

Several studies have demonstrated the great potential of AR in education. For example, research by Akçayır & Akçayır (2017) unveiled that AR can increase learning motivation and student engagement, as well as improve conceptual understanding. Additionally, research by Ib'añez & Delgado-Kloos (2018) concluded that AR in science education significantly improves students' understanding of abstract concepts that are difficult to teach through conventional methods. Another study conducted by Radu (2014) confirmed that AR can reduce misconceptions in science through more concrete and easily understandable interactive visualisations.

In the context of solar system learning, several AR-based media have been developed and tested for effectiveness. Research by Yilmaz (2014) developed an AR application that allows students to visualise the planets in the solar system in three dimensions. The results of this study displayed an increase in students' understanding of solar system material. Another study by Yilmaz (2016) exhibited that the use of AR in learning not only increases learning satisfaction but also fosters a positive perception of the science material being learned. Thus, AR has proven to be an effective tool in addressing the challenges of teaching abstract concepts in elementary school.

However, although the potential for using AR in science education is quite promising, existing solutions are subject to certain restrictions. One of the main limitations identified is the lack of audio integration in AR-based educational media. Many AR applications rely solely on three-dimensional visualisations and text without providing audio narration. In fact, research by Mohammed et al. (2022a) suggested that multimodality integration in learning media—particularly the combination of visuals, text, and audio—can significantly enhance learning effectiveness. Audio elements can enrich students' learning experiences, help them understand complex information, and cater to auditory learning styles that are often overlooked.

The limitations of AR learning media without audio elements are evident in studies such as that conducted by Wojciechowski & Cellary (2013), in which AR media focused solely on three-dimensional visualisation without supporting narration. Research by Avila-Garzon et al. (2021) also indicated that the AR-based learning models developed rely on text as supplementary explanations, without audio. In contrast, Di Serio et al. (2013) argued that the use of audio in learning media can enhance learners' emotional engagement with the material, which ultimately has a positive impact on their learning outcomes. A study by Wu et al. (2013) added that learning media that do not account for the diversity of learners' learning styles, such as auditory learning styles, risk making learning less inclusive and less effective.

The analysis of previous solutions and the existing limitations of this study proposed the development of a new educational tool called PlanetARia. PlanetARia is an educational tool based on augmented reality technology designed to help students learn about the solar system in a more immersive and multimodal way. The main innovation of PlanetARia is the integration of three-dimensional visualisations of the planets in the solar system with interactive audio narration that provides coherent and engaging additional explanations. With the inclusion of audio elements, PlanetARia is expected to overcome the constraints of previous AR learning media, enrich the learning experience, and enhance students' conceptual understanding.

The theoretical framework underlying the development of PlanetARia cognitivism theory, specifically Mayer's (2001) theory of multimedia, which states that learners learn more effectively when they receive information through a combination of text, images, and audio. According to Mayer, combining various media formats can reduce students' cognitive load and enhance their understanding of the learning material. Additionally, Kolb's (1984) experiential learning theory serves as a crucial foundation, as the use of AR provides students with the opportunity to directly experience and interact with learning objects in a virtual form, thereby strengthening the formation of their cognitive schemas.

This study aims to develop the PlanetARia learning medium on solar system material for sixth-grade elementary school students. PlanetARia is expected to serve as a concrete example of how AR technology can create more immersive, inclusive, and effective science learning that enhances students' understanding of abstract concepts.

METHOD

This study employed the Design and Development (D&D) research method using the ADDIE model (analysis, design, development, implementation, and evaluation). This research method and model were deemed appropriate because they are relevant and easy to use in product development (Rachma et al., 2023). The stages of this study are presented in Figure 1.

During the analysis phase, the researcher conducted needs analysis, curriculum analysis, and content analysis. The needs analysis by interviews with teachers and classroom observations aimed at identifying the students' needs for learning materials that align with their characteristics. Additionally, the curriculum analysis focused on the Merdeka Curriculum to determine the appropriate content to develop. Then, the content analysis defined the scope of the content to be developed.

Based on the analysis results, the researcher proceeded to product design. At this stage, the researcher defined learning objectives, developed instructional materials aligned with these objectives, created a product concept, and selected the applications to be used as tools during the development phase.

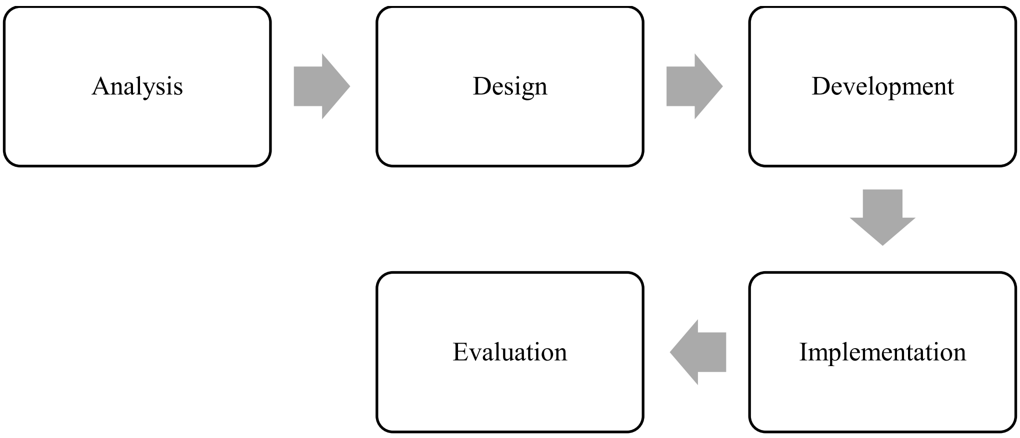

Figure 1. The ADDIE Model

The development process was based on data from analysis and planning. The researchers developed the PlanetARia learning media using the Assemblr EDU app to create augmented reality and the Canva app to design markers. Once the development process was complete, limited testing and evaluation were conducted by system and content experts. Then, a validation instrument employing a questionnaire using a Likert scale was administered to the system and content expert validators. The system expert validation was conducted by a software developer specialising in application development. Additionally, a content validation was conducted by a lecturer at a private university in Bogor who holds a master's degree in elementary education and is an elementary school teacher in Bogor. This expert validation aimed to gather suggestions and feedback for refining the PlanetARia learning media.

The next stage was implementation. Implementation was carried out after the product was deemed suitable by the system and content experts. The PlanetARia learning media was tested directly on 30 sixth-grade students to determine their responses to the product. The data was then collected, processed, and analysed to become the basis for an evaluation aimed at addressing shortcomings in the PlanetARia.

Research setting and participants

The participants in this study consisted of 30 sixth-grade elementary school students from a school in Bogor City. The students included 17 boys and 13 girls.

Data collection and analysis

Data for this study were obtained through interviews, observations, document analysis, and questionnaires. Interviews were conducted with sixth-grade teachers to identify students' needs for learning media appropriate to their characteristics. Interview indicators included teachers' understanding of difficulties with solar system material and their expectations regarding learning media. Observations were conducted on the students to assess their behavior and habits in science learning, as well as their level of interest in using technology for learning. A document review was conducted to analyse learning outcomes for Phase C of the Merdeka Curriculum, specifically in the Natural and Social Sciences (IPAS) subject. The indicators examined included the relevance of the material to be learned by sixth-grade students.

A total of three questionnaires were designed using a 1–5 Likert scale to assess validity and determine students' perceptions of the product. The first questionnaire was administered to subject matter experts to ensure that the PlanetARia media content aligns with the curriculum and the characteristics of sixth-grade students, that the visualisations of objects correspond to the actual objects, and that the content is didactically appropriate and suitable for use. The second questionnaire was administered to system experts to ensure the product's visual elements and system functionality operate effectively. The third questionnaire was administered to sixth-grade students to measure their perceptions regarding the three main aspects of the media: visualisation, content, and ease of use.

The data was then analysed descriptively. Data from interviews, observations, and document reviews underpin the development of the augmented reality-based learning media. The results of the validation by subject matter experts, system experts, and student response questionnaires regarding the PlanetARia media were analysed using Formula 1, with scoring criteria developed from a 1–5 Likert scale, as presented in Table 1.

$$P = \frac{Total\ score}{Total\ maximum\ score} \times 100\% \quad [1]$$

Table 1. Scoring criteria

Score	Criteria
5	Excellent
4	Good
3	Fair
2	Poor
1	Very poor

The validation scores were categorised to determine the product's validity level. The validity levels of the PlanetARia media, as determined by systems experts and subject matter experts, are presented in Table 2.

Table 2. PlanetARia Validity Level Categories

Percentage	Description
81%-100%	Valid, suitable for use
61%-80%	Fairly valid, suitable for use with some revisions
41%-60%	Less valid, suitable for use with major revisions
25%-40%	Invalid, not suitable for use

RESULTS

Data analysis

An analysis of the curriculum and student characteristics formulated the learning objectives. The resulting learning objective is "students will be able to analyse the characteristics of the planets in the solar system." The product to be developed is a learning medium using augmented reality, covering material related to the characteristics of Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Augmented reality was chosen as the learning medium for this material because the solar system is difficult to observe directly with the five senses. This medium is also tailored to learning styles (visual, auditory, kinaesthetic) and current trends.

Design of the PlanetAria

The PlanetAria learning medium is developed in the form of cards using Augmented Reality (AR) technology equipped with audio. In this case, the cards function as markers that must be scanned using a smartphone. The cards contain images, names, and barcodes. The images include Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.

The development process for the PlanetARia educational media utilised the Assemblr EDU and Canva applications. Assemblr EDU was used to incorporate augmented reality technology, while Canva was used to create marker designs. The markers used are cards of the size shown in Figure 2, with a weight of 260 gsm and a matte laminate finish. The A6 size is used for the cards to make them easier for students to use and store. The cards are finished with a matte laminate to prevent glare when scanned using the app.

Development of the PlanetARia learning media

a. Content development

The content was developed with a focus on the characteristics of Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. These characteristics include physical appearance, size, distance from the Sun, atmospheric properties, and the moons. The content development process involves gathering information from various sources, such as student textbooks and online searches.

b. Audio Development

The compiled content was then presented in a communicative language tailored to elementary school students. The audio production process involved converting text to audio using the TTSMaker platform. The audio production process is illustrated in Figure 3.

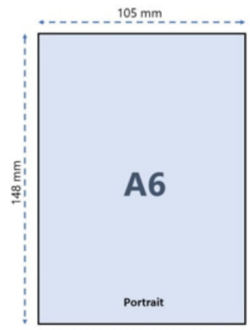

Figure 2. Marker size

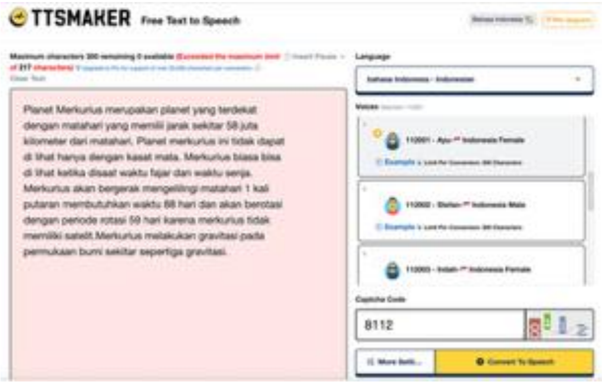

Figure 3. The audio creation process in TTSMaker

c. Creating augmented reality

The augmented reality design was created in the Assemblr EDU app by selecting elements that correspond to the prepared content, adjusting the element sizes, adding audio, and generating barcodes. The design process is shown in Figure 4.

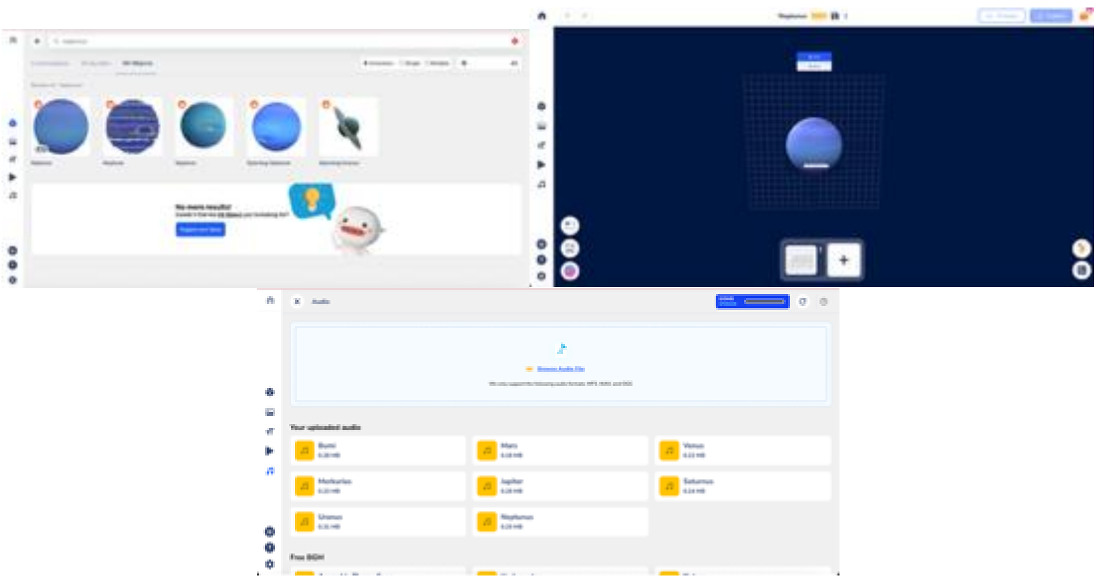

Figure 4. The process of creating augmented reality on Assemblr EDU

d. Creating markers

The markers were designed using the Canva app, using A6 paper size, and included planetary elements, object names, and a barcode downloaded from the Assemblr EDU app. The marker design is shown in Figure 5.

Figure 5. The process of creating the marker design

The design was then printed on the designated paper. The marker has two distinct sides. The front side displays an image and the planet's name, while the back side features a barcode that can be scanned to view the planet's AR. The PlanetARia marker or card is shown in Figure 6.

Figure 6. PlanetARia card

e. Limited testing

Limited testing was conducted to assess the success of the PlanetARia educational media. The testing process was carried out by the researcher, who also served as the developer. The appearance of the PlanetARia media during limited testing is shown in Figure 7.

Figure 7. Limited testing

During this limited testing process, the researcher tested several aspects, including barcode scanning, marker detection, and audio. The results of the limited testing can be seen in Table 3.

Table 3. Limited testing

No	Test	Process	Result
1	Barcode scanning	The barcodes for each planet can be scanned and redirect to the Assemblr EDU app	Successful
2	Marker detection	All markers can display 3D objects	Successful
3	Audio	The audio for all planets works properly	Successful

Based on Table 3, it was found that the barcodes on the PlanetARia cards can be detected by the Assemblr EDU app, the markers can correctly display 3D objects, and the audio functions properly. Therefore, it was concluded that the PlanetARia media is suitable for use.

f. Expert validation

Expert validation of the system and content was conducted to objectively test the PlanetARia learning media in terms of both system functionality and content relevance. System validation was performed by a software developer from a company in Australia. Content validation was conducted by a lecturer from a private university in Bogor and a teacher from a public elementary school in Bogor. The summary of the validation results is presented in Table 4.

Table 4. Summary of validation results for system and content experts

No	Content Expert	Percentage	Category
1	Validator 1	100%	Valid
2	Validator 2	96%	Valid
Average		98%	Valid
No	**System Expert**	**Percentage**	**Category**
1	Validator 1	96%	Valid
Average		96%	Valid
Overall average		97%	Valid

According to Table 4, the results of the expert validation of the PlanetARia system and content indicate an average score of 97%, classified as "valid." It was therefore concluded that, in terms of both the system and the content, the PlanetARia platform is suitable for use in the learning process.

Implementation

During the implementation phase, the PlanetARia educational tool was used to teach the solar system to 30 sixth-grade students at an elementary school in Bogor. The goal of this implementation was to introduce an Augmented Reality (AR)-based educational tool and to assess the students' perceptions of PlanetARia. The students used smartphones to scan markers embedded in the PlanetARia materials. After successfully scanning, they could explore the planets in the solar system by rotating, zooming in, zooming out, and listening to information delivered via the audio. This interactive experience was designed to help students understand the concept of the planets in the solar system in a more engaging and immersive way. The PlanetARia implementation process is shown in Figure 8.

A Likert-scale questionnaire was administered to students after they used the PlanetARia learning tool. This questionnaire measured students' responses to three main aspects: visualisation, content, and ease of use. The results of this questionnaire were analysed during the evaluation phase to assess the extent to which the tool successfully achieved the learning objectives and to identify areas requiring improvement in future versions of the tool.

Figure 8. Implementation of the PlanetARia learning tool

Evaluation

The evaluation of the PlanetARia learning media was based on the results of validation by system experts, content experts, and student responses. The validation results showed a score of 97%, indicating that the PlanetARia media is valid and suitable for use without revision. Further evaluation was conducted through an analysis of the questionnaire administered to students after they interacted with the PlanetARia media. The results of the student responses are in Table 5.

Table 5. Student responses to the media

No	Aspect	Criteria	Score				
			1	2	3	4	5
1	Visualisation	The PlanetARia cards look appealing			1	3	26
		The colors and shapes of the planets displayed in augmented reality are clear			4	6	20
2	Content	The planets displayed correspond to those in the solar system			3	5	22
		The PlanetARia media helps students understand the material on the planets in the solar system					
3	Ease of use	The PlanetARia media is easy to use			1	4	25

Based on Table 5, it was found that 87% (n = 26) of the students gave a very positive response to the PlanetARia card visualisation, while 67% (n = 20) of the students rated the clarity of the colors and shapes of the planets displayed in augmented reality as very good. Other responses were observed regarding the content: 73% (n = 22) of the students rated the alignment of the displayed objects with the content as very good. Additionally, 70% (n = 21) of the students stated that the PlanetARia platform was very helpful in understanding solar system content. Finally, regarding ease of use, 83% (n = 25) of the students responded that the PlanetARia media was easy to use. This indicates that the PlanetARia media is visually appealing, relevant in terms of content, and facilitates students' understanding of solar system material.

DISCUSSION

Testing and validation results indicate that PlanetARia is effective in enhancing students' learning experiences. The use of AR technology, combined with audio elements that accompany the three-dimensional visualisations of the planets, provides a more immersive and comprehensive learning experience. These results align with research by Wei et al. (2021), which emphasises that AR technology can increase student engagement, particularly in understanding abstract concepts that are challenging to explain through conventional methods. Research by Mohammed et al. (2022) also indicates that the integration of multimodal elements—including audio, visuals, and text—can improve conceptual understanding, a finding reflected in the PlanetARia test results.

One key factor underlying the success of AR is its ability to create a more interactive learning experience. In the context of science education, such as solar system topics, students often struggle to visualise objects far beyond their reach. Research by Basumatary & Maity (2023) shows that AR-based media can help students better understand abstract concepts such as the distances between planets or the scale of planetary sizes in the solar system—concepts that are extremely demanding to perceive with their five senses. This confirms that AR functions not only as a visual tool but also as a medium that connects digital information with the real world in a more profound way.

By comparison, some previous studies have developed AR applications that rely solely on three-dimensional visualisations without any audio elements. Research by Bower et al. (2014) indicates that while visually-based AR applications can aid in visual comprehension, the absence of narrative elements often limits deeper understanding of the taught material. A similar finding was reported in a study by Avila-Garzon et al. (2021), which indicated that AR applications using only text for supplementary explanations are less effective in enhancing student engagement and understanding. This is also consistent with the findings by Tiede et al. (2023), who state that the use of narrative elements, particularly audio, in AR can enhance student understanding and engagement more effectively than applications that rely solely on visualisation.

The strength of PlanetARia lies in its use of interactive audio elements that help clarify visual information and provide more in-depth explanations. This aligns with Mayer's multimedia theory (2020), which states that the combination of text, images, and audio can reduce students' cognitive load and enhance their understanding of the learning material. With the audio elements, learners not only view 3D models of the planets but also listen to narrative explanations that connect visual information with more complex concepts, such as size, distance, and planetary atmospheres. This concept is supported by research by Akçayır & Akçayır (2017), which demonstrates that the use of multimodality in technology-based learning can optimise information processing in the brain and help students process material more efficiently.

Furthermore, the test results show that PlanetARia successfully increased students' interest in learning about the solar system. A total of 87% of students responded positively to the engaging visualisations, and 73% stated that this medium helped them understand the material better. This is consistent with findings in a study (Silvi, 2022), which states that the use of AR in science education can increase learning satisfaction and improve students' conceptual understanding. Additionally, research by Peikos & Sofianidis (2024) also found that the use of AR in science education not only enhances understanding but also significantly increases students' interest in learning.

However, although PlanetARia has proven effective in improving students' understanding of solar system concepts, there are still challenges that need to be addressed. Some students may find it hard to use AR technology, especially those who are not accustomed to digital devices. Additionally, the use of AR technology requires adequate hardware and software, which may not always be available in all schools. According to Fearn & Hook (2023), the issue of limited access to technology is one of the main barriers to implementing AR in education, particularly in developing countries. Therefore, it is important to consider more affordable and accessible device-based solutions to ensure that all students can benefit from this technology.

Overall, the results of this study indicate that PlanetARia is not only effective in enhancing understanding of solar system concepts but also successfully addresses the limitations of existing AR learning media, particularly regarding multimodal integration. Through this approach, PlanetARia can meet the needs of various student learning styles—whether visual, auditory, or kinaesthetic—and provide a more inclusive and effective learning experience. This aligns with the findings by Tiede et al. (2023), who state that AR has a positive impact on accommodating various learning styles in the classroom.

CONCLUSION

The findings of this study indicate that the Augmented Reality (AR)-based PlanetARia learning tool is effective in enhancing students' understanding of solar system concepts. Based on the survey results, the majority of students found this tool engaging, easy to use, and helpful in grasping concepts that are difficult to explain using conventional methods. The use of audio elements accompanying the three-dimensional visualisation of the planets enriches the learning experience and reduces students' cognitive load, in line with multimedia theory. However, some limitations remain: some students required more time to understand how to interact with the AR objects. Therefore, it is recommended that an interactive tutorial be included at the beginning of use to accelerate user adaptation. Further research could enhance PlanetARia by integrating more learning materials and improving interactive features to enrich the learning experience across various disciplines.

Author contributions

The authors made significant contributions to the study's conception and design. The authors was in charge of data analysis, interpretation, and discussion of results. The final manuscript was read and approved by the authors.

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Conflict of interest

The authors declare that there is no potential conflict of interest.

Data availability statement

All data are available from the authors.

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