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Development of an AR-Based Solar System Flashcard Learning Media for Elementary Students Using the MDLC Method

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Abstract: Understanding the solar system remains challenging for elementary school students due to the abstract, spatial, and three-dimensional nature of astronomical concepts, which are often difficult to convey through conventional learning media. In response to this challenge, this study aims to develop and evaluate an Augmented Reality (AR)–based solar system flashcard learning media to support interactive and meaningful science learning at the elementary level. The learning media was developed using the Multimedia Development Life Cycle (MDLC) method, which consists of concept formulation, design, material collection, assembly, testing, and distribution stages. The AR application integrates three-dimensional planetary visualizations with flashcards to facilitate concrete representation of abstract concepts and enhance student engagement. The evaluation focused on usability and learning support through User Acceptance Testing (UAT), involving 10 elementary school students and employing a 3-point Likert scale questionnaire. The results indicate that the AR-based flashcard media is easy to use, functions reliably, and effectively supports students' understanding of solar system concepts. Students reported positive experiences in interacting with the learning media, suggesting its potential to improve motivation and conceptual comprehension in science learning. This study contributes to the development of innovative digital learning media that promotes inclusive and quality education by integrating emerging technologies into early science instruction. In alignment with Sustainable Development Goal (SDG) 4, the proposed AR-based learning media supports equitable access to engaging educational resources and enhances learning quality through interactive, technology-enabled instruction for elementary students.

Keywords: Augmented Reality Flashcards; Solar System; Elementary Education; Multimedia Development Life Cycle; Interactive Learning.

1. Introduction

Education is a multifaceted process involving various stakeholders, in which learning media play a critical role in supporting effective instruction. Recent advances in educational technology have expanded opportunities for teachers to present learning materials in more engaging and meaningful ways, particularly in Natural Science (IPA). One of the fundamental topics in Natural Science is the introduction of the Solar System [1]. However, limited availability of appropriate instructional teaching aids often reduces the effectiveness of material delivery, indicating the need for alternative learning media that can better support students' comprehension [2]. Integrating multimedia-based instructional media is therefore considered an effective approach, as it allows content to be delivered in a more communicative, visual, and in-depth manner [3].

Despite the availability of various learning media, many elementary schools still rely heavily on conventional instructional tools such as textbooks, static images, and basic visual aids [8]–[10]. These media are insufficient for explaining astronomical concepts, which are inherently abstract, large-scale, and not directly observable [11–12]. Research on in-service science teachers' conceptions of astronomy in Thailand indicates that astronomy is widely perceived as a difficult subject by both teachers and students due to its reliance on abstraction, spatial reasoning, relative motion, scale, and a high risk of misconceptions [13]. Consequently, students often develop misunderstandings regarding planetary size, movement, and characteristics, highlighting a mismatch between the complexity of the content and the limitations of traditional instructional media.

Augmented Reality (AR) has emerged as a promising technology to address these challenges. AR enables the real-time integration of two-dimensional and three-dimensional virtual objects into the real environment [4], creating interactive and dynamic learning experiences that can enhance student engagement [5]. In educational contexts, AR allows learners to observe and interact directly with learning objects, making it particularly suitable for topics that require spatial visualization and conceptual understanding, such as astronomy [4]. These characteristics position AR as a potential solution to improve the teaching and learning of abstract scientific concepts.

Flashcards are also recognized as an effective learning medium for elementary students, supporting conceptual understanding in science, vocabulary acquisition, reading skills, and storytelling abilities [14–16]. The integration of AR technology into flashcards further enhances their instructional value by enabling interactive visualization and experiential learning. Previous studies have demonstrated that AR-based flashcards can improve science literacy, learning outcomes in science topics such as the water cycle, vocabulary mastery, reading interest, and storytelling skills among elementary and early childhood learners [17–20].

Although previous studies have explored the use of AR and flashcards in education, there remains a research gap in the development of AR-based flashcard learning media specifically designed to support elementary students' understanding of solar system concepts through structured instructional design and interactive visualization. Existing solutions often focus on general AR visualization without integrating instructional design principles or are not tailored to the cognitive characteristics of elementary learners. Therefore, this study aims to develop and evaluate an AR-based Solar System flashcard learning media using the Multimedia Development Life Cycle (MDLC) method. The proposed learning media is intended to bridge abstract astronomical concepts with students' perceptual experiences, provide interactive and manipulable three-dimensional representations, and contribute to more effective and engaging elementary-level science learning.

2. Materials and Methods

The development of the Solar System Education AR application employed the Multimedia Development Life Cycle (MDLC) as the primary development framework. MDLC was selected because it is specifically designed for multimedia-based applications and provides a structured yet flexible process that supports the integration of visual assets, interactivity, and iterative refinement—key requirements in Augmented Reality (AR) learning media development [21]. Compared to general software development models, MDLC is more suitable for educational multimedia projects as it emphasizes content organization, user experience, and media integration rather than purely technical system functions.

In this study, MDLC was applied through six sequential phases: concept, design, material collecting, assembly, testing, and distribution. Each phase was adapted to support the instructional objectives and target users of the application.

2.1. Concept

In the concept phase, the learning problem was defined based on the difficulty elementary students face in understanding the solar system using conventional media. The target users were identified as elementary school students, with teachers acting as facilitators during classroom instruction. Learning objectives were formulated to support basic conceptual understanding of planetary order, characteristics, and spatial relationships. Augmented Reality–based flashcards were chosen as the instructional medium to allow students to visualize and explore solar system objects interactively during learning activities.

2.2. Design

The design phase focused on translating learning objectives into an interactive instructional flow suitable for classroom and independent learning. The application structure was designed to support simple navigation, age-appropriate interaction, and guided exploration using flashcards as AR markers. Storyboards and interaction flows were developed to ensure that each visual element, interaction, and information panel directly supported the intended learning outcomes.

2.3. Material Collecting

In this phase, instructional materials relevant to elementary science curricula were collected and prepared, including textual explanations of planets, audio narration, and three-dimensional planetary models. All materials were adapted to match students' cognitive levels and aligned with curriculum content to ensure relevance and instructional accuracy.

2.4. Assembly

During the assembly phase, the collected materials were integrated into an AR environment using multimedia development tools. Marker-based AR functionality was implemented to enable students to scan flashcards and interact with three-dimensional planetary models. This phase resulted in a functional prototype that allowed real-time visualization and exploration of solar system concepts.

2.5. Testing

Testing focused on evaluating the application's usability and functionality in a learning context. User Acceptance Testing (UAT) was conducted with elementary school students to assess ease of use, clarity of interaction, and the application's ability to support understanding of solar system concepts. Feedback from this phase was used to identify minor usability issues and confirm the application's readiness for learning use.

2.6. Distribution

The distribution phase involved preparing the application for use in real learning settings. The final version was packaged in a deployable format and accompanied by simple usage instructions, enabling teachers and students to use the application during classroom activities or independent learning sessions.

3. Results

This section will be presented based on each stage in the Multimedia Development Life Cycle (MDLC) method, so that the process flow of creation from concept formulation to the distribution stage is explained systematically and structured.

3.1. Concept

The concept phase involves defining the goals, target users, and overall functionality of the *Solar System Education AR* application. Based on the identified problem in the background namely the abstract nature of solar system concepts and the limitations of conventional instructional tools the primary objective is to develop an immersive AR-based learning medium that enhances visualization and promotes active engagement among elementary school learners. The application aims to display 3D planetary models, provide interactive information access, and project virtual planetary systems onto real-world surfaces or flashcards. The AR flashcard approach supports improved comprehension, consistent with recent studies highlighting the effectiveness of AR-based flashcards in elementary learning contexts

3.2. Design

The design phase establishes the system architecture, user interaction flow, and multimedia elements required. The application is structured to integrate AR visualization with interactive elements such as tapping and rotating 3D planetary models that can be seen on the Figure 1.

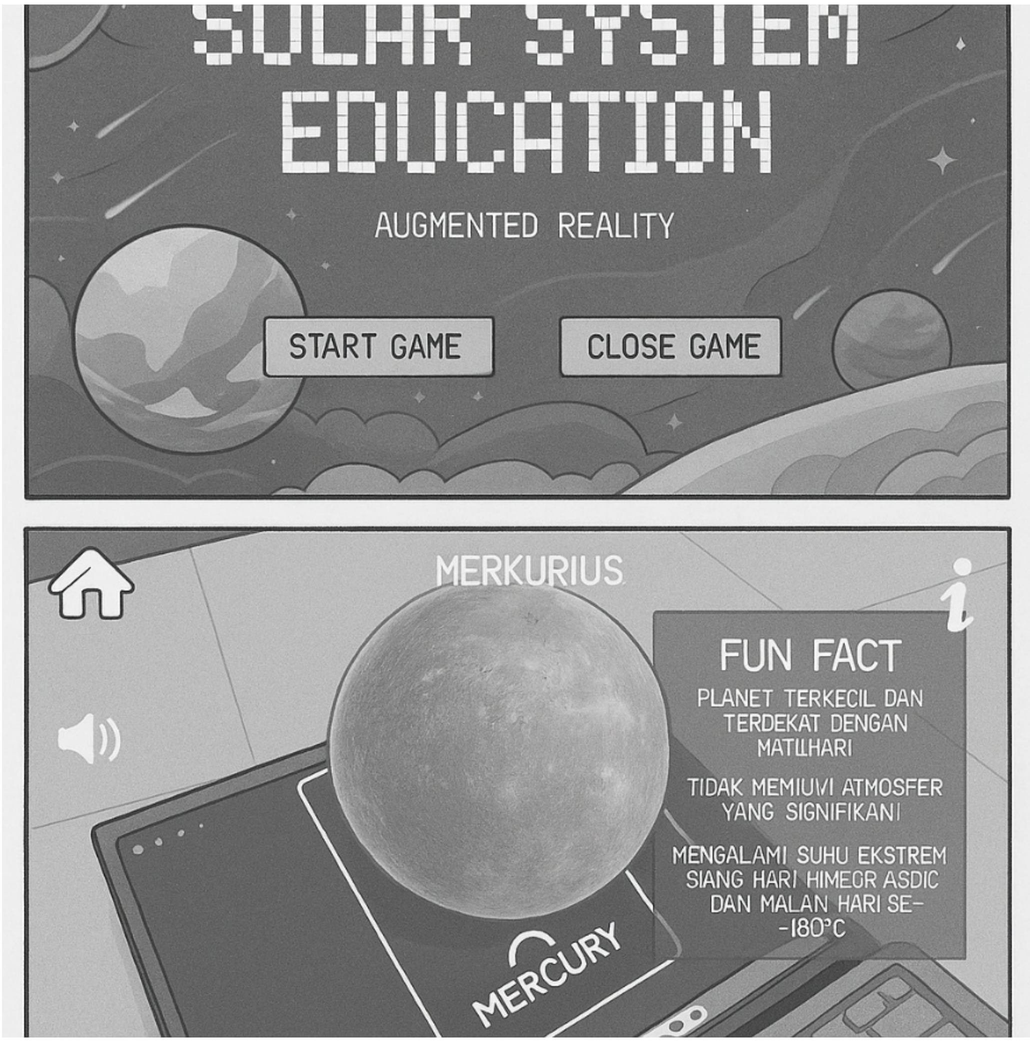


Figure 1. Application Storyboard

The interface design prioritizes simplicity and clarity to accommodate elementary learners' cognitive characteristics (Figure 1).

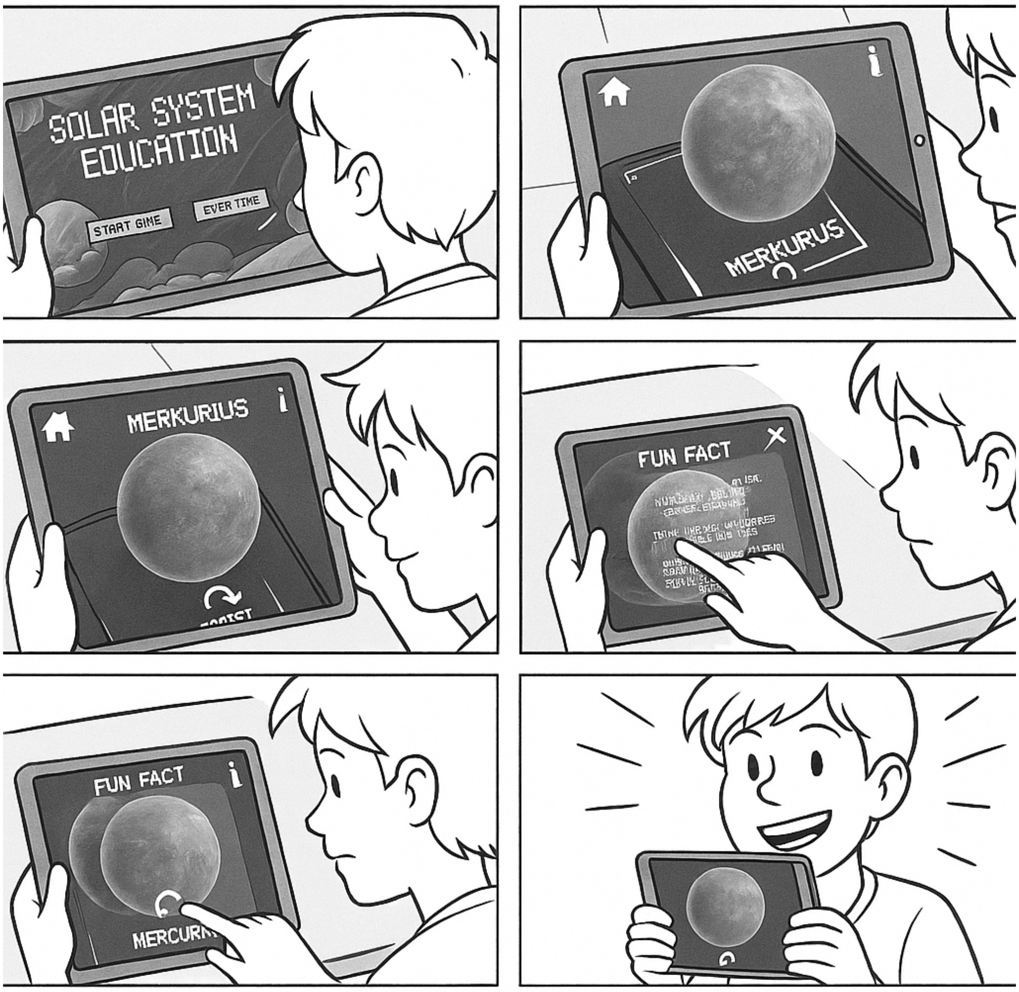


Figure 2. User Storyboard

The user storyboard developed in the Design Phase illustrates the intended user interaction flow for the *Solar System Education AR* application, serving as a visual guide for interface layout, navigation structure, and AR content behavior. Each frame depicts key actions such as opening the app, scanning a marker, viewing the 3D planet, accessing information panels, and interacting with UI elements ensuring that the design supports an intuitive, child-friendly learning experience. By visualizing these steps, the storyboard helps align user needs with system functionality, guiding developers in creating a coherent, usable, and engaging AR learning environment for elementary students.

On the Design phase also defines the technological components required, including:

- Unity Editor as the primary development environment for assembling assets and configuring application scenes.
- AR Foundation to support cross-platform AR features such as plane detection, real-time rendering, and light estimation.
- Vuforia for recognizing image targets or flashcards, allowing AR content to appear when physical cards are scanned.
- 3D planetary models representing the solar system with realistic textures, relative sizes, and animations sourced from Unity Asset Store.
- XR Interaction Toolkit for managing user interactions (e.g., tapping planets to reveal information).

3.3. *Material Collecting*

This phase involves gathering all digital assets and learning materials required for the application. Planetary 3D models, textures, animations, sound effects, and background music are collected from the Unity Asset Store and other licensed sources. Scientific information regarding planetary characteristics (size, orbit, composition, temperature) is compiled to ensure accuracy. Flashcard markers are designed for Vuforia's Image Target recognition system, enabling a physical–digital integration where students can view planets emerging from printed cards.

3.4. *Assembly*

The assembly phase is the core development stage, where all multimedia elements and technical components are integrated using Unity Editor. Developers configure AR Foundation to detect flat surfaces and render 3D planets within the user's physical environment. Vuforia is integrated to enable marker-based AR, allowing the system to project planets onto flashcards or designated images. The XR Interaction Toolkit is implemented to allow users to interact with planetary models by tapping to display information, rotating planets, and observing their animations. Lighting, shading, and rendering features are adjusted to enhance realism, supported by AR Foundation's Light Estimation, which aligns virtual object lighting with ambient real-world conditions. Animations, such as planetary rotation, are also implemented to provide a dynamic and immersive experience.

Figure 3. Create an image target on a flashcard

Figure 3 showed the process of creating the image target by importing the image into the *Assets* folder to be used as the Image Target Card. Once the image has been successfully imported, select the Image Target Card and drag the image into the *Image Target Behavior* component. The image will then be displayed on the canvas.

Figure 4. 3D objects creation

Figure 4 showed the process of creating the 3D ojects by adding the 3D object to be displayed by importing the corresponding model or image. Drag the imported file onto the Image Target Card to associate it with the target. Adjust the position, orientation, and scale of the object to ensure proper visualization during the AR experience.

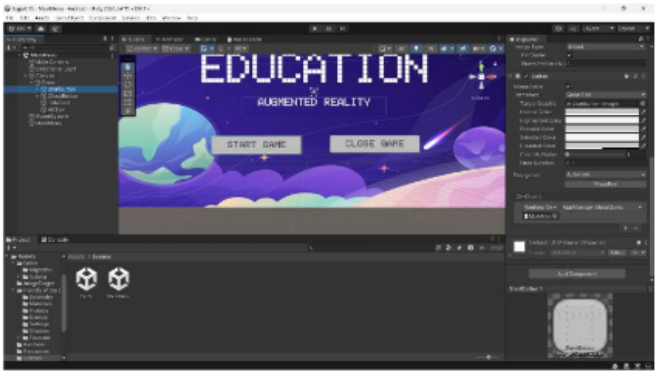


Figure 5. Activating start and close button

The final step shown in Figure 5 ensures that users can initiate or exit the application. In the Inspector panel, the Start Button is configured so that when pressed, it triggers the App Manager function *MulaiGame*, which directs the user to the next scene (e.g., to begin the AR experience).

Figure 6. Features of the Solar System Education AR Application

The *Solar System Education AR* application includes several interface elements that support user navigation and interaction. The Start Game (1) button serves as the entry point to begin the AR exploration, while the Close Game (2) button allows users to exit the application quickly. The volume icon (3) activates audio narration that explains the characteristics of the scanned planet, and the rotate icon (4) enables users to rotate the 3D planet model to view details from different angles. The home icon (5) functions as a navigation control to return to the main menu, whereas the "i" icon (6) provides additional information about the displayed planet. Together, these features are designed to deliver an intuitive, informative, and interactive learning experience.

Table 1. Flashcard Design and Scanned AR Display Samples

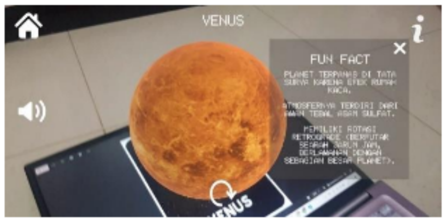
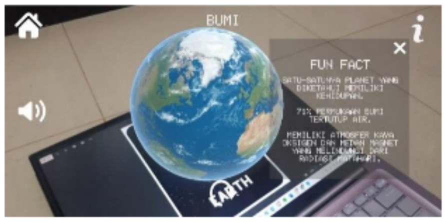
Flashcard	Results
	
	
	
	

Table 1 displays flashcards developed in the Solar System Education AR app samples (the are more flashcards design), along with the results of scanning the displayed objects. Each row in the table shows details of each flashcard, including the planet name, a representative image, and key information displayed after scanning.

3.5. *Testing*

Testing was conducted to evaluate the functionality, usability, and visual performance of the Solar System Education AR application in conditions representative of real classroom use by elementary school students. This section reports the functional testing scenarios and their results, ensuring that each core feature operated as intended prior to user evaluation.

- Functional Testing Results

Functional testing focused on verifying the performance of AR tracking, 3D rendering, and user interaction features. The procedures included testing the application's ability to detect flashcard markers, render 3D planetary models in real time, and respond to user inputs such as rotating the model, activating audio narration, and opening information panels. Testing was conducted across several devices to ensure that the AR features functioned consistently without crashes, delays, or rendering errors.

Table 2. Functional Testing Scenarios and Results

Test ID	Test Scenario	Test Procedure	Expected Outcome	Result
FT-01	Marker detection	Scan solar system flashcard using device camera	Flashcard marker detected and AR content activated	Pass
FT-02	3D model rendering	Display planetary 3D model after marker detection	3D model rendered correctly and proportionally	Pass
FT-03	Model interaction	Rotate 3D model using touch gesture	Model rotates smoothly without lag	Pass
FT-04	Audio narration	Activate audio description icon	Audio plays clearly and matches displayed planet	Pass
FT-05	Information panel	Open planet information panel	Textual information displayed correctly	Pass
FT-06	Navigation controls	Use start, home, and back buttons	Navigation functions correctly without errors	Pass
FT-07	System stability	Run application continuously for learning session	No crash, freeze, or rendering error observed	Pass

The functional testing results indicate that all tested features performed as expected. The AR tracking system successfully detected flashcard markers and displayed corresponding three-dimensional planetary models in real time. User interactions, including object rotation, audio activation, and information panel access, functioned smoothly and responsively. No critical system errors, crashes, or visual rendering issues were observed during testing across the tested devices. These results confirm that the application met the functional requirements and was technically ready for subsequent usability evaluation with elementary school students.

- Usability Testing with Elementary Students

After the completion of functional testing and system stabilization, User Acceptance Testing (UAT) was first conducted during the late development stage to verify that the Solar System Education AR application met basic functional and user requirements. Following this stage, usability testing was carried out on the stable version of the application to evaluate ease of use, interface clarity, and suitability for elementary school students as the target users. Usability testing involved 25 Grade 4 elementary school students, selected to represent a typical classroom environment and to ensure sufficient data stability for quantitative analysis in a pilot usability study. This sample size is considered appropriate for usability evaluation in educational technology research, particularly when involving children and questionnaire-based analysis.

The evaluation employed a 5-point Likert scale ranging from strongly disagree (1) to strongly agree (5), as presented in Table 2, to assess students' perceptions of usability and acceptance. During the testing sessions, students were asked to navigate the application interface, scan flashcards, interact with AR-based planet models, and access informational features independently. The usability testing focused on assessing interface clarity, ease of navigation, and students' ability to understand the presented information without external assistance. In addition to questionnaire responses, observational data were collected to identify potential usability issues, such as misinterpretation of icons, difficulty in aligning the device with markers, or confusion when switching between planetary objects. These observations were used to support the quantitative findings and to identify areas for further refinement of the application.

Table 3. List of Questions

No	Question	Strongly Agree (SA)	Agree (A)	Neutral (N)	Disagree (D)	Strongly Disagree (SD)
1	Is the application easy to use?					
2	Is the application interface clear and easy to understand?					
3	Can you scan the flashcards easily?					
4	Is the planetary information easy to read and understand?					
5	Does the application help you understand the solar system better?					

The questions presented in Table 3 were designed to evaluate the usability of the *Solar System Education AR* application from the perspective of elementary school users. These five items address core usability principles, including ease of use, clarity of the interface, interaction quality, information readability, and learning effectiveness. The results of usability testing can be seen in Figure 7.

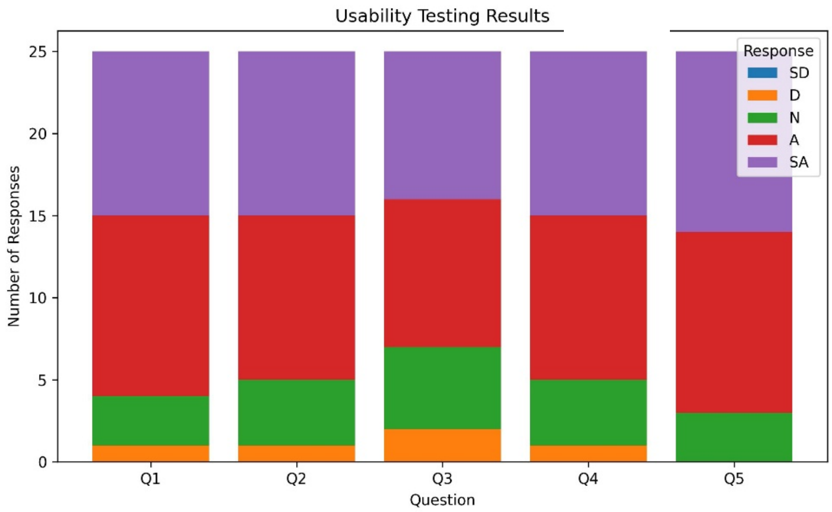


Figure 7. Usability testing results

Usability testing was conducted after system stabilization to evaluate the ease of use, interface clarity, information readability, and perceived learning support of the Solar System Education AR application from the perspective of elementary school students. The evaluation consisted of five usability-related questions (Table 3), measured using a 5-point Likert scale, ranging from Strongly Disagree (SD) to Strongly Agree (SA), with a total of 25 respondents. As illustrated in Figure 7, the results indicate a strongly positive usability perception among participants. For all five questions, responses were dominated by the Agree (A) and Strongly Agree (SA) categories, demonstrating that most students found the application easy to use and the interface clear and understandable. In particular, Questions Q1 and Q2 show high concentrations of agreement, indicating that the application's basic usability and interface design are well suited for elementary school users.

Regarding interaction features, Question Q3 (flashcard scanning) shows slightly higher Neutral (N) and Disagree (D) responses compared to the other items, as reflected in the stacked bar distribution. This suggests that while most students were able to scan flashcards successfully, some required a brief adjustment period to become familiar with the AR interaction mechanics. Nevertheless, positive responses (A + SA) still constitute the majority for this item. For information readability (Q4), the graph shows a strong dominance of Agree and Strongly Agree responses, indicating that the planetary information presented in the application was generally easy to read and understand. Similarly, Question Q5 received the highest proportion of Strongly Agree responses, suggesting that students perceived the application as effective in supporting their understanding of the solar system.

Notably, Strongly Disagree responses were absent across all questions, and Disagree responses were minimal, indicating that no major usability barriers were encountered. These quantitative findings are consistent with observational data collected during the testing sessions, where most students were able to complete tasks independently. Minor usability challenges were observed, such as occasional difficulty aligning the device camera with flashcards and brief confusion when switching between planetary objects; however, these issues did not significantly affect task completion or overall user experience. Overall, the results presented in Figure 7 confirm that the Solar System Education AR application demonstrates good usability, clear interface design, and positive learning support, supporting its suitability as an interactive learning medium for elementary school students.

- Compatibility Testing

Compatibility testing was conducted on Android-based devices (Android 10–14) to ensure stable AR performance across different hardware specifications. The evaluation focused on AR marker detection, tracking stability, 3D rendering quality, and overall system responsiveness. Based on the results, Android 10 was established as the minimum supported version for reliable system operation. The application demonstrated consistent AR projection and smooth interaction across all tested devices. Minor performance variations were observed on lower-end devices; however, these did not significantly affect usability or learning interaction.

Table 4. Android Devices and Compatibility Results

Device Model	Android Version	Screen Size	Test Result
Samsung Galaxy A51	Android 10	6.5 inch	Pass
Xiaomi Redmi Note 10	Android 11	6.4 inch	Pass
Samsung Galaxy S21	Android 12	6.2 inch	Pass
Oppo Reno 8	Android 13	6.4 inch	Pass
Samsung Galaxy S21 FE	Android 14	6.4 inch	Pass

Overall, these results confirm that the Solar System Education AR application is compatible with Android devices running Android 10 or higher, supporting consistent performance in elementary learning environments.

- Test Results and Revisions

Observations from all testing stages were analyzed to guide improvements. Minor issues were identified, such as occasional delays in marker recognition under low lighting and the need for clearer button icons for young users. These findings informed revisions aimed at improving system responsiveness, enhancing marker detection accuracy, and refining navigation flow to support more intuitive user interaction.

Overall, the testing process demonstrated that the application performed reliably and was well-received by elementary learners, confirming its feasibility and effectiveness as an interactive learning tool for understanding the solar system.

3.6. Distribution

The final phase involves preparing the application for deployment. This includes packaging the application into APK or iOS build formats, documenting installation procedures, and testing the application in classroom settings. The distribution strategy focuses on accessibility for teachers and students, enabling integration into science lessons that involve solar system exploration. Future updates and enhancements may include expanding AR flashcard sets or adding interactive quizzes to reinforce learning.

4. Discussion

The development of the Solar System Education AR application follows a structured software and multimedia engineering process, culminating in a user-centered prototype that is both technically functional and pedagogically suitable. The successful integration of AR tracking, 3D asset rendering, interactive controls (rotation, info, audio), and a clearly designed user interface demonstrates that it is feasible to translate abstract astronomical concepts into concrete, manipulable visualizations. The design and implementation choices (e.g., marker-based flashcards, intuitive icons, responsive UI) correspond well with best practices in AR educational development, supporting ease of use and cognitive accessibility for elementary-level users.

The usability testing involving 10 elementary students yielded strongly positive feedback: most respondents selected “Agree” across questions evaluating ease of use, clarity of interface, scanning ease, readability of planetary information, and perceived effectiveness in enhancing understanding of the solar system. Importantly, none selected “Disagree,” indicating that the system did not present major usability barriers. These findings align with prior research indicating that AR-based learning media can significantly improve user engagement, conceptual understanding, and learning outcomes in school settings. For instance, studies have documented how AR improves spatial comprehension and motivation when learners interact with complex 3-D phenomena that are otherwise difficult to visualize [22]–[24].

One important interpretation is that the high usability scores suggest the design decisions successfully lowered entry barriers for young learners: simple navigation, clear visual cues, and interactive 3D models collectively support both cognitive load reduction and intrinsic motivation. This supports the hypothesis that AR media can serve as an effective bridge between abstract scientific content and learners’ perceptual understanding, which is consistent with broader findings in AR education literature [25], [26]. Furthermore, the successful marker detection and rendering across devices underline the technical soundness of the system as a necessary condition before scaling or curriculum-wide adoption.

However, some limitations and considerations arise. While the majority responded positively, a subset selected “Neutral” (especially regarding clarity of information panels), which suggests that textual content may still need adaptation in readability or presentation for younger students. This matches earlier research which notes that while AR visualizations enhance engagement, information density and complexity must be carefully managed to avoid cognitive overload [27]. Moreover, the study’s sample size (10 students) is modest; a larger, more diverse sample and a controlled pre-/post-knowledge test would provide stronger evidence regarding actual learning gains, beyond usability and user satisfaction.

Another important caveat is the dependency on environmental conditions (light, marker quality) for optimal AR performance. As noted in usability observations and corroborated by other studies, inconsistent lighting or poor marker quality may degrade tracking accuracy, reduce user experience quality, or even discourage use [28]. This suggests that for real-world classroom deployment, guidelines or support (e.g., lighting, marker printing quality) will be important to ensure consistent usability.

5. Conclusions

This study presents the development and evaluation of an Augmented Reality–based solar system flashcard learning media for elementary students using the MDLC framework. The contributions of this research are threefold. First, from a technical perspective, the study delivers a functional AR application that enables interactive visualization of abstract astronomical concepts through three-dimensional representations. Second, from a usability perspective, the evaluation results indicate that the application is intuitive, easy to use, and suitable for elementary learners, supporting its feasibility for real classroom implementation. Third, from an educational perspective, the application addresses the limitations of conventional learning media by providing engaging, visualization-rich instructional support aligned with elementary science curricula.

In relation to Sustainable Development Goal (SDG) 4: Quality Education, this study contributes to improving learning quality by promoting inclusive access to innovative digital learning resources and enhancing students' understanding of complex scientific concepts through technology-enabled instruction. The AR-based learning media supports more engaging and learner-centered educational practices, particularly at the elementary level.

Future research should extend beyond usability evaluation to include experimental studies that examine the impact of AR-based learning media on students' learning outcomes, conceptual understanding, and knowledge retention compared to traditional instructional approaches. Further development may also explore content expansion, interactive assessments, and teacher or parent monitoring features to support broader and more sustainable educational implementation..

References

[1] A. R. Hakim, A. S. Budi, and D. Kurniawan, "Development of interactive multimedia learning media to improve students' understanding," *Journal of Physics: Conference Series*, vol. 1402, no. 7, p. 077003, 2019. https://doi.org/10.1088/1742-6596/1402/7/077003

[2] J. Zhang, Y. Li, and H. Chen, "Immersive technologies in primary education: A systematic review of augmented reality learning environments," *Frontiers in Education*, vol. 10, p. 1577721, 2025. https://doi.org/10.3389/feduc.2025.1577721

[3] I W. Darma, I G. Margunayasa, and G. A. P. S. Trisna, "Interactive multimedia based on project-based learning model using Articulate Storyline 3 material for fifth-grade elementary school," *Jurnal Ilmiah Sekolah Dasar*, vol. 8, no. 2, pp. 215–226, 2024. https://doi.org/10.23887/jisd.v8i2.59642

[4] A. S. Rahmawati, R. H. Putra, and L. Y. Pratiwi, "Augmented reality-based learning media to improve science conceptual understanding in elementary education," *Jurnal Penelitian Pendidikan IPA*, vol. 10, no. 10, pp. 857–866, 2024.https://doi.org/10.29303/jppipa.v10i10.8586

[5] M. Al-Sayed, R. K. Hassan, and T. Nguyen, "Enhancing student engagement through augmented reality in secondary biology education," *Frontiers in Education*, vol. 10, p. 1628004, 2025. https://doi.org/10.3389/feduc.2025.1628004

[6] M. D. Firmansyah and Nagano, "Perancangan dan Pengembangan Simulasi Gerak Hewan Jenis Equidae Menggunakan Metode MDLC (Multimedia Development Life Cycle) pada Animasi 3D," Journal of Information System and Technology, vol. 03, no. 02, pp. 252–256, Jul. 2022, Accessed: May 28, 2025. https://doi.org/10.37253/joint.v3i2.6756

[7] Khairunnisa, M. R. Akbar, Usanto, S. Ningtyas, and . Aziz, MULTIMEDIA : Teori dan Aplikasi dalam Dunia Pendidikan. PT. Sonpedia Publishing Indonesia, 2023. Accessed: May 28, 2025. https://books.google.co.id/books?id=15-5EAAAQBAJ

[8] D. T. Ratnasari, Y. Sulaeman, and J. Jumanah, "Analysis of the need for digital teaching materials in Indonesian language learning in elementary schools," *Al-Ishlah: Jurnal Pendidikan*, vol. 17, no. 3, pp. 4138–4148, 2025. https://doi.org/10.35445/alishlah.v17i3.5641

[9] C. R. Kirana, W. Sopandi, A. Sujana, and F. S. D. Putri, "Transformation of elementary science education through the RADEC model and digital learning based on augmented reality for human digestive system," *International Journal of Elementary Education*, vol. 9, no. 1, pp. 30–37, Feb. 2025.https://doi.org/10.23887/ijee.v9i1.87630

[10] I. A. Mubaidilla, "Digital media vs. conventional media: Effectiveness of learning in primary education," *Pedagogik Journal of Islamic Elementary School*, vol. 8, no. 2, pp. 750–766, 2025. https://doi.org/10.24256/pijies.v8i2.7762

[11] S. Jansri and W. Ketpichainarong, "Investigating in-service science teachers' conceptions of astronomy and determining the obstacles in teaching astronomy in Thailand," *International Journal of Educational Methodology*, vol. 6, no. 4, pp. 745–758, 2020. https://doi.org/10.12973/ijem.6.4.745

[12] P. S. Bretones, "Astronomy education research: Impact and future directions," *EPJ Web of Conferences*, vol. 200, p. 01022, 2019. https://doi.org/10.1051/epjconf/201920001022

[13] E. Harits and R. Rahmawati, "The Role of Observatory in Observing and Studying Celestial Objects for Elementary School Students," *J. Teach. Innov. Media*, vol. 4, no. 2, pp. 45–53, 2024. https://doi.org/10.35746/jtim.v7i2.566

[14] A. N. Dafitri, "The Effectiveness of Flashcard Media in Enhancing Vocabulary Mastery of Young Learners," *J. Pedago.*, vol. 12, no. 1, pp. 55–63, 2024. https://doi.org/10.21067/jped.v12i1.8071

[15] R. Pramadanti, "The Effectiveness Of Using Flashcards To Improve Vocabulary In Speaking English For Elementary School Students," *Simpati*, vol. 1, no. 3, pp. 213–222, Jun. 2023. https://doi.org/10.59024/simpati.v1i3.238

[16] Annisyah and E. Munisah, "The Effectiveness of Flash Cards in Improving Reading Skills of Elementary School Students," *J. Lesson Learn. Stud.*, vol. 8, no. 1, pp. 46–54, 2025. https://doi.org/10.23887/jlls.v8i1.90298

[17] A. Setiawan, I. Yunitasari, D. J. Pratiwi, Y. I. Dela, and W. A. Jatmiko, "Developing Augmented Reality-Based Flashcards to Enhance Science Literacy in Elementary Schools," *Pedagogia*, vol. 17, no. 1, pp. 90–103, Jul. 2025. https://doi.org/10.55215/pedagogia.v17i1.49

[18] K. K. Listiani and W. E. Paramartha, "Augmented Reality Based Flashcard Media to Improve Student Learning Outcomes on the Topic Water Cycle V Grade Elementary School," Int. J. Elementary Educ., vol. 9, no. 1, pp. 160–169, Feb. 2025. https://doi.org/10.23887/ijee.v1i1.94634

[19] R. Hafidah, M. Yusuf, and S. Subagya, "Using Augmented Reality Flashcards To Improve English Vocabulary Mastery for Children Aged 4–5 Years," *ThufuLA J. Inov. Pendidik. Guru RA.*, vol. 10, no. 2, pp. 271–281, Dec. 2022. https://doi.org/10.21043/thufula.v10i2.17159

[20] T. Ruswanti, M. Jannah, R. Fitri, A. Kristanto, U. Dewi, and Y. M. Lasarus, "Effect of Augmented Reality Flash Card Media on Reading Interest and Storytelling Ability in Children Aged 5–6 Years," *Int. J. Emerg. Res. Rev.*, vol. 3, no. 2, p. 000096, Apr. 2025. https://doi.org/10.56707/ijoerar.v3i2.96

[21] S. M. T. Alessi and S. R. Trollip, *Multimedia for Learning: Methods and Development*, 3rd ed. Allyn & Bacon, 2001.

[22] C.-H. Lai and Y.-H. Chang, "Impacts of Augmented Reality Apps on First Graders' Motivation and Performance in English Vocabulary," *Comput. Educ.*, vol. 175, pp. 104–123, 2021. https://doi.org/10.1016/j.compedu.2021.104315

[23] N. Lubis, Risnawati, R. Vebrianto, and M. F. Hamdani, "Pengaruh Media Pembelajaran Berbasis Augmented Reality terhadap Pemahaman Konsep dan Minat Membaca Siswa Kelas 5 Sekolah Dasar," *Pendas*, vol. 10, no. 2, pp. 1–12, Jun. 2025. https://doi.org/10.23969/jp.v10i2.27176

[24] W. Mu'minah, K. Koderi, S. Basyar, and Z. Zulhannan, "Literature Review: Pemanfaatan Augmented Reality Dalam Pembelajaran Bahasa Arab," *J. Kaj. Pend. Islam*, vol. 4, no. 1, pp. 48–59, Jan. 2025. https://doi.org/10.58561/jkpi.v4i1.169

[25] P. Maulidiah, A. Sya, and L. Kusumawati, "Efektivitas Media Pembelajaran Augmented Reality (AR) dalam Meningkatkan Hasil Belajar Kognitif Siswa pada Pelajaran Geografi di Kelas X SMAN 36 Jakarta," *JPIG*, vol. 8, no. 2, pp. 75–84, Sep. 2023. https://doi.org/10.21067/jpig.v8i2.8619

[26] T. P. Socrates and F. Muffit, "Efektivitas Penerapan Media Pembelajaran Fisika Berbasis Augmented Reality: Studi Literatur," *EduFisika*, vol. 7, no. 2, pp. 1–10, Jun. 2022. https://doi.org/10.59052/edufisika.v7i1.19219

[27] R. Baki *et al.*, "Usability Analysis of Augmented Reality-Based Learning Applications for Kids: Insights from SUS and Heuristic Evaluation," in *Advances in Design and Digital Communication IV*, Dec. 2023. https://doi.org/10.1007/978-3-031-47281-7_10

[28] J. Mercier *et al.*, "Impact of Geolocation Data on Augmented Reality Usability: A Comparative User Test," *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, vol. XLVIII-4/W7-2023, pp. 133–140, Jun. 2023. https://doi.org/10.5194/isprs-archives-XLVIII-4-W7-2023-133-2023