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DEVELOPMENT OF SOLAR SYSTEM TEACHING AIDS WITH MANIPULATIVE VIRTUALIZATION CONCRETE AND DIGITAL AUGMENTED REALITY

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ABSTRACT

Teaching aids, through the use of real objects, have been employed to describe the science concept in learning. Innovation in teaching aids, mainly digital access and Augmented Reality-based virtualization, is necessary to keep up with the fast advancement of ICT. This study aims to design solar system teaching aids using manipulative virtualization concrete and digital AR. This study employed the ADDIE Research and Development (R&D) to achieve its objectives. It involved several stages: Analysis, Design, Development, Implementation, and Evaluation. It created solar system teaching aids employing manipulative virtualization and digital AR. The validation findings for content experts are 88%, media and technology experts are 86% and teacher or user responses are 88%. All three validations met the very feasible requirements. The average percentage of validation score is 87,33%, indicating that the criteria are very feasible. This study concludes that solar system teaching aids with AR-based concrete and digital virtualization manipulation effectively improve students' conceptual understanding of the solar system while addressing compliance and learning content. These teaching aids combine physical models with an augmented reality application. The AR application enriches the learning experience by projecting dynamic, scaled visuals of planetary orbits and positions in real-time, complementing the physical models of the solar system, where students can interact with tangible, three-dimensional representations of the solar system. This dual approach provides an exciting and comprehensive learning experience, especially for abstract astronomical concepts.

Keywords: augmented reality; manipulative; solar system; teaching aids; manipulative virtualization concrete

INTRODUCTION

Real objects have been employed as teaching aids to help better understand the science concept in learning (Khan et al., 2019; Steffe & Ulrich, 2020; Suyanto et al., 2022). Visual aids, such as real objects, can help students learn science concepts more effectively (Suyatna, 2019; Dewi et al., 2019; İbili et al., 2020). Effective learning with good learning outcomes requires a thorough understanding of the concept.

Science learning activities during the Industrial Revolution 4.0 and Society 5.0 are supposed to be aimed at preparing students for the 21st century, which should be focused on developing attitudes, skills, and knowledge mastery of both concrete and abstract science materials (Satori et al., 2019; Oliveira & de Souza, 2022).

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In addition, employing static or animated images or videos to teach complex and abstract science is less effective than employing child-friendly technology (Milkaite & Lievens, 2020). Innovation in teaching aids, mainly digital access and virtualization using Augmented Reality (AR), is essential as information and communication technology advances. Augmented Reality (AR) is a real-time projection of virtual objects (2D or 3D) onto a real-world environment (Lee, 2020; Bogomolova et al., 2021; Hamzah et al., 2021; Hutahaean et al., 2022; Dewi et al., 2024).

Solar systems are astronomy material taught from elementary to university levels. A creative teaching method is needed to teach solar system concepts to students. Furthermore, one of the ways to deal with this topic is through visual aids, which can help students understand concepts or knowledge comprehensively (Fitriani & Fibriana, 2020; Taufiq et al., 2021; Jumini et al.,2021).

The solar system teaching aids having been employed in the learning process are insufficient due to limitations, such as limited interactivity and integration with technology that combines virtual objects into a three-dimensional environment (Wang et al., 2022; AlGerafi et al., 2023; Fitria, 2023). Despite the accessibility of ICT-based solar system education tools, this gap remains there. Employing 2D and 3D visualization technology can improve students' understanding of spatially complicated subjects, such as solar systems (de Moraes Rossetto et al., 2023). Employing sophisticated teaching aids remains limited in many educational settings due to limited resources, teacher training, and access to technology (Alqahtani & AlNajdi, 2023).

Regardless of the developments, the maximum potential of 3D and augmented reality (AR) tools for improving solar system learning is neglected. Tene et al. (2024) found that these tools increase participation and make it easier to comprehend complex astronomical concepts. Additionally, Aguilar et al. (2024) point out how AR-supported teaching aids encourage real-time engagement and object spatial manipulation, both essential for learning subjects that need spatial relationships. To close this gap and make solar system education more immersive and interactive, a thorough evaluation of the available resources is required, as is an effort for broader implementation of ICT-based teaching aids.

Current literature has principally addressed AR's general science applications, with little emphasis on specific domains like the solar system. While Moraes Rossetto et al. (2023), Durukan et al. (2023), and Ferrari et al. (2024) point out AR's effectiveness in visualizing complex concepts, there is a demand for materials that combine AR technology with interactive, hands-on teaching models to improve spatial understanding of the solar system. This study proposes a new approach that blends digital AR and physical manipulation to optimize student learning experiences and improve conceptual understanding.

Augmented Reality (AR) technology can improve science teaching aids by allowing students to engage with complex and abstract concepts in real time (Diao & Shih, 2019; Extremera et al., 2020; Setiawaty et al., 2024). Based on the previous statement, solar system props must be designed using AR-based concrete and digital virtualization manipulation. This study aims to improve students' understanding of science concepts, particularly solar system, through using solar system teaching aids with manipulative virtualization concrete and digital AR.

METHODS

This study employed the Research and Development (R&D) approach with the ADDIE model to systematically accomplish its objectives through the stages of Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). Each stage of the ADDIE cycle was broken down into technical research steps. The ADDIE model was selected for its organized and iterative characteristics, which allow for systematic development and validation of educational resources. The model corresponds to design objectives and final implementation outcomes. The ADDIE development model cycle (Cheung, 2016) applied in this study is presented in Figure 1.

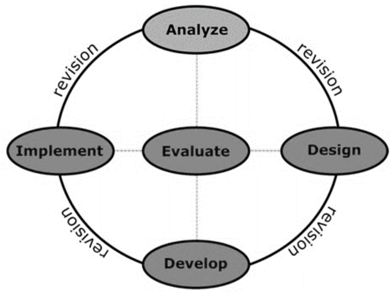

Figure 1. The ADDIE Model Research Step (Branch, 2009)

In designing solar system teaching aids with manipulative virtualization concrete and digital AR, several analysis steps were carried out, such as the needs assessment process, problems (needs) identification, and task analysis performance. These steps include reviewing curriculum needs and gathering data from interviews with three teachers, five prospective teachers, and three educational experts to identify particular gaps in current teaching aids.

The design stage involves creating solar system teaching aids employing manipulative virtualization concrete and digital AR. Product design is conceptual and guides the subsequent development process. The development process involves designing solar system teaching aids using manipulative virtualization concrete and digital AR. At the design stage, a conceptual framework for using solar system teaching aids of manipulative virtualization concrete and digital AR was developed. The conceptual framework is transformed into a product ready for implementation during the development stage. At the implementation stage, the design of solar system teaching aids with manipulative virtualization concrete and digital AR were tested in classrooms or other locations to ensure their effectiveness. After implementing solar system teaching aids with manipulative virtualization concrete and digital AR, an initial evaluation was conducted to gather feedback on their effectiveness. This evaluation stage was also thoroughly conducted at each stage of the ADDIE processes. The evaluation results provide feedback for users of the solar system teaching aids. Revisions were made based on review results or missing requirements for the solar system teaching aids with manipulative virtualization concrete and digital AR.

A questionnaire was developed to evaluate the feasibility of solar system teaching aids, which combine manipulative virtualization through concrete and digital augmented reality (AR). Data were collected quantitatively using a 5-point Likert scale to assess feasibility and qualitatively through open-ended feedback provided by respondents. The feasibility study included evaluations from material content experts, media and technology experts, and prospective users, such as teachers or lecturers. Material content experts examined content quality, compliance, and language, while media and technology experts evaluated instructional aids' visual communication and technological capacity. Teachers provided feedback on the learning process, materials, and visual communication.

Descriptive analysis was employed in the data analysis technique to examine data characteristics. The data were analyzed descriptively using developmental data and questionnaire responses (Göb et al., 2007). Likert scale questionnaire was employed with five scales: very feasible, feasible, quite feasible, less feasible, and not feasible, as presented in Table 1.

Table 1. Assessment with a Likert scale

Statement	Score
Very feasible	5
Feasible	4
Fairly feasible	3
Less feasible	2
Not feasible	1

To examine questionnaire responses, the average answer was derived based on each respondent's score using the following formula:

$$P = \frac{n}{N} x 100\%$$

Where:
P: Percentage of responses
n: The total score obtained
N: Total criteria score

The results obtained are then presented according to Table 2.

Table 2. The Feasibility Score and Criteria

Percentage (%)	Criteria
81 - 100	very feasible
61 -80	feasible
41- 60	fairly feasible
21 - 40	less feasible
0 - 20	not feasible

(de Moraes Rossetto et al., 2023)

RESULTS AND DISCUSSION

According to the analysis stage, the development of solar system teaching aids with manipulative virtualization concrete and digital AR leads to needs assessment: (1) The solar system's material characteristics include common knowledge that Earth is one of several planets orbiting the Sun in our solar system, observing various planets and objects in our solar system, and gaining an understanding of scale when comparing planetary sizes. (2) The solar system teaching aids with manipulative virtualization concrete and digital AR were specified in terms of dimensions, sizes, and material types; (3) The problems (needs) Identification of solar system teaching aids with AR-based concrete and digital virtualization manipulation and analysis were carried out to develop solar system teaching aids with manipulative virtualization concrete and digital AR.

The design stage involves developing solar system teaching aids with manipulative virtualization concrete and digital AR. The product design is an AR-based digital version of the sun as the center and surrounded by planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune). The product design remains conceptual and guides the subsequent development process.

During the development stage, solar system teaching aids were designed using manipulative virtualization and digital augmented reality (AR). The design of the solar system teaching aids allows for using three-dimensional objects made of plastic. However, there are limitations in visualizing the distance between the sun and planets due to unrealistic comparison scales. Therefore, a flexible Android app and AR marker are needed to improve solar system visualization. The app will project three-dimensional virtual objects into a real-world environment in real-time (Shchur & Shakhovska, 2019; Liu & Tanaka, 2021; Vernica et al., 2022).

To exemplify the physical design and base structure of the solar system teaching aids, Figure 2 shows the initial design of the solar system model, with manipulative virtualization through tangible objects. This model depicts the Sun at the center, surrounded by each planet in the correct order, to visually comprehend the solar system's structure. The physical design allows users to monitor and change each planet's position relative to the sun, encouraging hands-on learning through direct interaction.

Figure 2. Design of Solar System Teaching Aids with Manipulative Virtualization Concrete

Figure 3 shows the base part of the solar system teaching aids, which serve as a visual guide for planet placement in the solar system. The base arrangement with labeled planetary orbits is a reference for identifying and placing planets around the Sun. The base design promotes spatial awareness of planetary configuration and orbits, which is necessary for understanding planetary motion and scale.

Figure 3. Base Part Design of Solar System Teaching Aids with Manipulative Virtualization Concrete

The development stage includes integrating an Android-based solar system AR application and markers. This app features an AR Camera menu, Solar System Material, Instructions, Developer Information, and Exit. The AR Camera is accessed to view an augmented reality representation of the solar system constellation. The Sun and planets move in real-time orbits and distances. The materials menu provides information literacy on various theories that comprehensively explain the concept of the solar system. The Help menu explains how to use the AR Solar System application and its navigation options. The developer details menu shows who created the AR Solar System application. Menu Exit is a button for quitting the application. The solar system teaching aids were created using augmented reality and digital virtualization. They also include a printed guide catalog.

Figure 4. Solar System AR App Opening View

Figure 4 shows the initial look of the Solar System AR app. The initial interface provides users with an intuitive entry point, setting the stage for an engaging and comprehensive learning experience about the solar system.

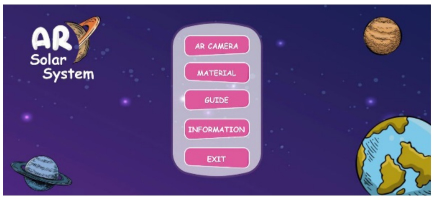

Figure 5. Main Menu Display of AR Solar System Application

Figure 5 shows the main menu, which arranges the app's functionality, including the AR camera, lesson content, and informational resources, ensuring smooth navigation and usability.

Figure 6. An AR version of Saturn Display Example

Figure 6 displays Saturn in a realistic 3D representation, illustrating the AR features. These features improve spatial awareness by allowing learners to study planetary formations deeply.

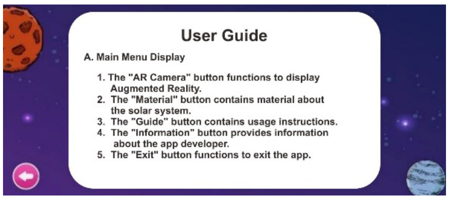

Figure 7. Display Instructions for Use

To help users, the application presents a clear instructional tutorial, which, as seen in Figure 7, explains how to use the app's features and access educational tools.

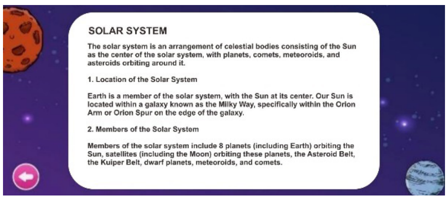

Figure 8. Solar System Material Content Display

Figure 8 shows the application's comprehensive learning materials on solar systems, which provide users with extensive insights into astronomical concepts. Eventually, Figure 9 presents the developer menu, which reveals information about the developers and collaborators, recognizing the teamwork behind this innovative educational tool.

Figure 9. Developer Menu Display

During the implementation stage, the designed solar system teaching aids with manipulative virtualization concrete and digital AR were tested in classrooms to ensure their effectiveness. This study focuses on validating the solar system teaching aids through expert questionnaires. Tables 3, 4, and 5 indicate the feasibility of the research results based on expert validation (in terms of material, media and technology experts, and teachers as users).

Table 3. Results of Material Expert Validation

No	Aspect	Percentage Validation Score (%)	Criteria
1	Content Quality	89	very Feasible
2	Content Compliance	85	Feasible
3	Language	90	very Feasible

Table 4. Validation Results of Media and Technology Experts

No	Aspect	Percentage Validation Score (%)	Criteria
1	Visual Communication	87	Very feasible
2	Technology	85	Very feasible

Table 5. Teacher Response Results

No	Aspect	Percentage Validation Score (%)	Criteria
1	Learning Process	86	Very Feasible
2	Learning Material	88	Feasible
3	Visual Communication	90	Very Feasible

Expert validation resulted in an average of 88% for material experts, 86% for media and technology experts, and 88% for teachers or prospective users. The validation findings showed an average percentage of 87,33%, which falls within the range of 81-100, indicating high feasibility. It can be included that the integration of AR technology improves spatial knowledge of astronomical concepts and encourages self-regulated learning. Integrating physical and digital manipulation tools allows students to explore freely while developing critical thinking and problem-solving skills. This corresponds with 21st-century educational goals, which stress interactive, technology-driven learning methods.

After applying the solar system teaching aids with manipulative virtualization concrete and digital AR, an evaluation was conducted to gather feedback from experts and respondents on their effectiveness. The findings indicated that material experts provided the lowest percentage of validation scores for content adherence. The solar system teaching aids with manipulative virtualization concrete and digital AR cover a broader range of topics than the curriculum requires. This aims to improve the comprehensiveness of learning materials. The media and technology experts validated the teaching aids and found them very feasible. However, they recommended providing guidelines for use and activity sheets. Teachers reported the lowest response rates for learning materials. The teacher suggested summarizing media content and composing a terminology list to help students understand solar system concepts (Cohen & Holstein, 2018; Hew et al., 2018; Noetel et al., 2022).

The teachers' responses reported that employing solar system teaching aids with manipulative virtualization concrete and digital AR improved student understanding. The solar system teaching aids with manipulative virtualization concrete and digital AR allow students to independently explore the content (De Paolis & Bourdot, 2019; Radianti et al., 2020; Belisle, 2020; Harambam, 2020). This solar system teaching aids with manipulative virtualization concrete and digital AR can help students develop self-regulated learning (Torres, 2022; Stanney et al., 2022).

The solar system teaching aids with manipulative virtualization concrete and digital AR provide students with a fully engaged and authentic learning experience. By employing solar system teaching aids with manipulative virtualization concrete and digital AR, students' imaginations can be promptly improved in the real world (Yamamoto et al., 2018; Earle et al., 2021; Anderson et al., 2021; Lehman-Wilzig, 2021; Moallem, 2021; You et al., 2022). Solar system teaching aids with manipulative virtualization concrete and digital AR can trigger students' mindset to understand the solar system concept and develop problem-solving skills (Gómez Galán et al., 2019; Rivera et al., 2021).

This study's limitation is the lack of realistic scale representation of planets and the Sun in the physical model. Although the teaching aids with manipulative virtualization concrete offer an engaging experience, they fall short in accurately representing distances and scale, which are important for understanding spatial relationships in the solar system. In addition, the AR application generated in this study lacks advanced user interaction features, including UI/UX components designed for educational engagement. Development of the current app can improve its interface to be more user-friendly and engaging, leading to more outstanding learning outcomes.

Future studies are supposed to focus on developing a more technologically advanced AR-based teaching tool with accurate scaling for planetary distances and sizes. It is recommended that integrating detailed UI/UX features can improve the effectiveness of AR applications in education by making complicated concepts more accessible (Yang et al., 2021; Singh & Ahmad, 2024). Further studies could focus on adapting AR teaching aids to individual students' learning styles and pace, as recommended by Papakostas et al. (2022) and Liu et al. (2024).

CONCLUSION

This study concludes that solar system teaching aids with AR-based concrete and digital virtualization manipulation effectively improve students' conceptual understanding of the solar system while addressing compliance and learning content. These teaching aids combine physical models with an augmented reality application. The AR application enriches the learning experience by projecting dynamic, scaled visuals of planetary orbits and positions in real-time, complementing the physical models of the solar system, where students can interact with tangible, three-dimensional representations of the solar system. This dual approach provides an exciting and comprehensive learning experience, especially for abstract astronomical concepts. The safe and child-friendly solar system teaching aids with AR-based concrete and digital virtualization manipulation can improve students' understanding of concepts in science.

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