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Research Article

# Solar System Learning Innovation through Augmented Reality: Increasing Student Concept Solar System

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**ABSTRACT**

**Purpose of the study:** Students' conceptual understanding of Solar System topics remains low due to the abstract nature of astronomical phenomena and the limited use of interactive visual learning media. This study aims to develop AR-based Solar System learning media that are valid, practical, and effective in improving students' conceptual mastery.

**Methodology:** The research employed a Research and Development approach using the 4D model. Participants comprised 46 eighth-grade students from Muhammadiyah 1 Junior High School in Palembang, selected through purposive sampling. Data collection involved teacher interviews, expert validation (3 experts), student practicality questionnaires (9 students) and pretest-posttest assessments (46 respondents),. The instruments included closed-ended Likert-scale items, open-ended feedback, and concept mastery tests. Data analysis was conducted using the Guttman scale for validity, the Likert scale for practicality, and the N-gain test for effectiveness.

**Main Findings:** The developed AR learning media achieved a validity score of 100%, a practicality score of 96.82% (very practical), and high effectiveness, with an average N-gain of 0.71. Students' posttest scores showed substantial improvement compared to pretest results, indicating enhanced understanding of planetary motion, rotation, and revolution.

**Novelty/Originality of this study:** The findings confirm that AR-based learning media effectively facilitate conceptual change by transforming abstract Solar System concepts into concrete, interactive experiences. The novelty of this study lies in integrating realistic 3D visualization, curriculum-oriented design, and effectiveness testing. The results imply that AR media can serve as a viable instructional innovation in science education, particularly for abstract topics that require spatial reasoning.



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## 1. INTRODUCTION

Understanding concepts is an important aspect of science learning because it forms the basis for students to build meaningful scientific knowledge. However, various studies have shown that the mastery of junior high school students' concepts in Solar System material is still relatively low. This is characterized by the many misconceptions that still arise regarding the position of the planet, the motion of revolution, the rotation of the earth, and astronomical phenomena such as the phases of the moon and eclipses [1]. The low level of mastery of this concept is due to several factors, including the predominantly conventional learning method, the limitations of three-dimensional visual media, and the lack of interactive learning experiences [2]. Solar System material is classified as abstract because many objects cannot be observed directly by students, so understanding the concept is very dependent on visualization abilities and spatial representation [3]. Data states that more than 60% of junior high school students still have misconceptions about the concept of revolution and rotation of the earth, which has implications for errors in explaining day and night events and seasonal changes [4]. Similar findings were also obtained who report that students tend to understand the Solar System only textually without being able to relate relationships between objects conceptually [5].

Learning Natural Sciences, especially on material solar system, students often have difficulty understanding the position, relative size, and movement of planets with respect to the sun. This is due to astronomical properties that cannot be observed directly in everyday life [6]. Therefore, the use of AR-based learning media is a potential solution to provide more concrete and interactive learning [7]. Conceptual understanding in (IPA) requires students to integrate spatial reasoning, visualization, and causal explanations of phenomena [8]. Studies consistently report that students often rely on rote memorization rather than conceptual [9], reasoning when studying topics related to the Solar System, leading to misunderstandings about planetary order, relative distances, and motion patterns [10], [11]. Such misunderstandings tend to persist unless instructional interventions explicitly support conceptual change through visual and interactive representations [12], [13]. Advances in educational technology have opened up new opportunities in improving the quality of science learning. One approach that is starting to be widely implemented is the use of based media Augmented Reality (AR).

AR is a technology that combines virtual objects with the real world interactively and in real time [14]. AR is able to improve students' learning experiences through immersive and interesting visualizations, so that abstract concepts can be more easily understood [15]. AR that allows 3 D visualization of objects and direct interaction with Solar System models [16]. Research shows that using AR can increase learning engagement (*engagement*) and help students build a deeper understanding of the concept [17]. Several studies have shown that the application of AR in science learning can improve understanding of concepts and students' learning motivation. For example, research by [14]. developed AR media for solar system materials and found significant improvements in student learning outcomes. In addition, AR media provides a pleasant learning experience and increases knowledge retention [4]. Augmented Reality (AR) has been identified as a promising technology capable of presenting three-dimensional, interactive visualizations; however, many AR studies focus primarily on learning outcomes without systematically examining media validity, practicality, and alignment with curriculum demands. Augmented Reality has been widely recognized as an effective instructional technology for science education due to its ability to present abstract concepts in a concrete and interactive manner [9], [18]. Research demonstrates that AR-based learning environments enhance students' motivation, engagement, and conceptual understanding by enabling direct manipulation of virtual objects [19], [20]. In the context of Solar System learning, AR facilitates exploration of planetary motion, rotation, and revolution through 3D visualization, which is difficult to achieve using traditional media [21].

Although previous studies have confirmed the positive impact of AR on learning outcomes, including animations and simulations, can improve learning outcomes. However, most existing learning media still rely on two-dimensional representations and offer limited interactivity, which hinders the development of students' spatial reasoning. Augmented Reality (AR) has been identified as a promising technology for presenting interactive three-dimensional visualizations; however, many AR studies focus on learning outcomes without systematically testing the validity of the media, its practical feasibility, and its suitability for curriculum requirements. Furthermore, few studies explicitly report the implementation of AR media on students' concept mastery. Therefore, this study aims to fill this gap by systematically developing and evaluating AR learning media about the Solar System using the 4D Model, as well as testing its impact on students' concept mastery.

AR-based learning media allows students to interact directly with three-dimensional models of the solar system, observe planetary movements, and visually study the characteristics of each planet. This medium can thus create a deeper and more meaningful learning experience than conventional methods [22]. Therefore, this study aims to develop and evaluate AR-assisted Solar System learning media and to examine its effectiveness in improving students' conceptual mastery. The research questions guiding this study are: (1) How to develop a valid and practical AR-assisted Solar System learning medium? (2) How to examine its effectiveness in improving students' conceptual mastery?

## 2. RESEARCH METHOD

This research uses research and development methods (R&D) with reference to 4D models. This model was chosen because it is oriented towards producing effective and viable learning media products. The stages passed include: definition stage (Define), planning stage (Design), development stage and stage Disseminate.

This model was selected because it emphasizes systematic product development and iterative evaluation to ensure instructional validity and effectiveness. The participants in this research consisted of: 46 students in class VI of elementary school as a user in a limited trial. Research location in Muhammadiyah 1 Middle School Palembang**.** Participant selection was carried out using techniques purposive sampling, namely based on criteria of relevance to the use of AR learning media and students' basic abilities in understanding solar system material [23].

Data is collected through several techniques, namely 1) Interviews and preliminary observations for teachers to find out how far they have mastered the student's concept. 2) Expert validation questionnaire carried out by 3 media experts to assess aspects of the feasibility of AR media content, appearance and interactivity. 3) Study results test in the form of pretests and posttests, they are used to measure the improvement in students' understanding of concepts before and after using AR media.

Data analysis is carried out quantitative and qualitative, in the expert validation questionnaire analyzed using average score to determine the level of eligibility of the product based on the guttman scale criteria 1 = yes and 0 = no. In the questionnaire on the practicality of products with scale criteria of 1-4. After processing, the average score results are obtained which will then be matched with the practicality level category of the learning media that refers to the table 1.

Table 1. Categories of practicality levels

| Answer Category | Scale |
|---|---|
| 3.26 – 4.00 | Very Practical |
| 2.51 – 3.25 | Practical |
| 1.76 – 2.50 | Not Practical |
| 1.00 – 1.75 | Very Unpractical |

Analysis of test data is carried out by adding up the scores obtained from each item of questions that have been carried out by students. Data on student learning outcomes analyzed using N-gain test to see an improved understanding of concepts before and after learning [24].

Table 2. Gain Criteria

| N-Gain | Criteria |
|---|---|
| <g> 0.70 | High |
| 0.30 <g> 0.70 | Medium |
| <g> < 0.30 | Low |

## 3. RESULTS AND DISCUSSION

This research develops augmented Reality (AR) based Solar System learning media using 4D models (Define, Design, Develop, Disseminate). The research subjects were 46 students in class VIII of Junior High School Muhammadiyah 1 Palembang. Curriculum analysis shows the Merdeka Curriculum emphasizes the skill of interpreting astronomical phenomena, not just memorizing them. Teachers support the use of AR because it is able to transform abstract concepts into interactive visuals. Many educator interviews show that there is a positive tendency towards teachers' perception of AR, where teachers see AR as a medium able to transform abstract concepts into visual and interactive representations, making it easier for students to understand concepts such as the composition of the Solar System, rotation of revolutions, and eclipse phenomena. In the interview, there was a statement that AR "allows students to see 'size, relative distance and movement' so that it becomes more concrete. The pedagogical implication is that teachers tend to support the use of AR to strengthen the exploratory phase and the strengthening of concepts, particularly on spatially charged topics. The results also showed the positive effects of AR on the motivation and spatial visualization of learners [25].

Materials are prepared according to junior high school science learning achievements. Draft media in the form of 3D planetary objects, narratives and AR markers. The development process began with the creation of three-dimensional models of planets, the Sun, and other celestial bodies using 3 D modeling software. Each object is designed with details that resemble its original condition. Once all models are complete, the next step is to integrate the object into the AR platform. Here's a prototype view of AR learning media.

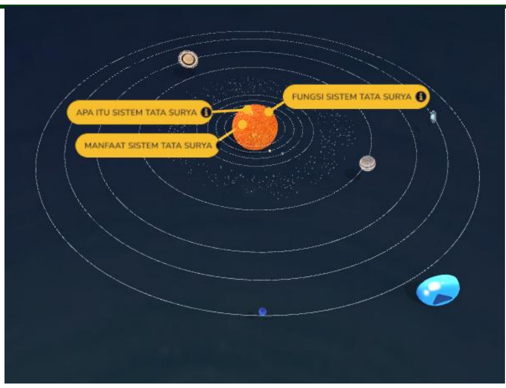

Figure 1. 3D Model Solar System

Figure 2. Planet Earth 3D Model

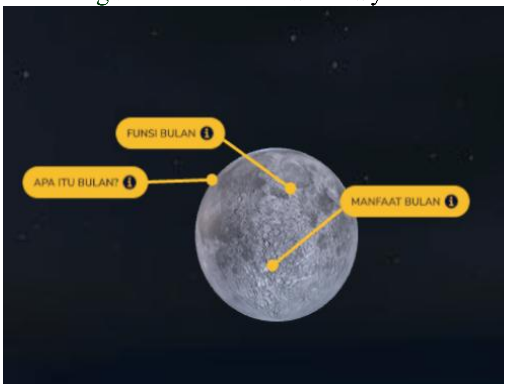

Figure 1. Moon 3D Model

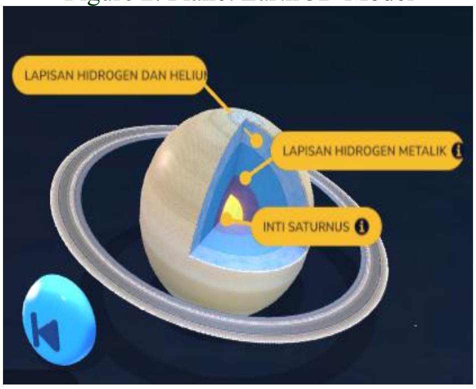

Figure 3. 3D model of the planet Saturn

Once the AR media prototype has been completed, the product is then validated by a materials expert, media expert and linguist to assess content quality, media feasibility and language usage. The validator provides input and all expert input is used to improve the media to achieve feasibility before it is implemented by students.

Table 3. Validation expert recapitulation

| Aspect | Percentage (%) | Category |
|---|---|---|
| Content Expert | 100 | Very Valid |
| Learning Design Expert | 100 | Very Valid |
| Media Expert | 100 | Very Valid |

Based on a recapitulation table of validation experts. AR prototypes were validated by content, design and media experts with average results 100% (very valid). Practicality tests by learners yielded average scores 95.03% (very practical). The next stage is a practicality test carried out by 9 students. The practicality test aims to assess the ease of use of media by students, clarity of instructions, visual attractiveness, and smooth interaction between users and AR applications. Learner responses are used to identify initial weaknesses in the media so that further revisions can be made before the media is used more widely.

Table 4. Results of improvements based on expert judgement

| Statement | Total Score | (%) |
|---|---|---|
| Learning media can be used easily via smartphone devices | 9 | 100 |
| The appearance of learning media is interesting so that you are more enthusiastic about learning activities | 8 | 88.89 |
| The material in learning media is easy to understand | 8 | 88.89 |
| The images presented correspond to the material | 9 | 100 |
| The type of writing/text used in learning media is easy to read | 9 | 100 |
| The language used in learning media is easy to understand | 9 | 100 |
| This learning medium makes it easier to learn independently | 9 | 100 |
| Images on learning media can be seen clearly | 8 | 88.89 |
| This learning medium trained me to master material about Earth and Solar System material | 9 | 100 |
| This learning medium encouraged me to be more active in learning | 9 | 100 |

| Statement | Total Score | (%) |
|---|---|---|
| activities | | |
| Augmented Reality media helped me imagine the shape and objects of the sky in the solar system | 9 | 100 |
| I can better distinguish the characteristics of each planet | 9 | 100 |
| I have no difficulty running Augmented Reality media | 9 | 100 |
| Instructions for using Augmented Reality media are easy to understand | 9 | 100 |
| Average | 8.78 | 96.82 |
| Category | | Very Practical |

Based on the assessment results in the table, the learning medium of the Augmented Reality assisted Solar System obtained an average score 8,78 by percentage 96.82%, which shows the category very practical for use in learning. All statements get percentages above 85%, some aspects even achieve perfect scores (100%). These results show that media is easily accessible via smartphone, attractive displays, and the materials and language used are easy for students to understand. The aim of this dissemination stage is to introduce the media to users more widely and implement it in classroom learning. This effectiveness test was prepared to assess the extent to which the use of Augmented Reality assisted Solar System learning media can improve students' mastery of concepts and support their involvement in the learning process.

Based on the pretest and posttest results graph in Figure 4.5, it can be seen that there has been a very significant increase in students' mastery of concepts after using Augmented Reality assisted Solar System Learning Media. The pretest average value is **50,22** shows that before the use of media, students' initial understanding of the material was still in the low to medium category. After learning interventions with AR media, the average posttest score increased to **87,83**, signifying an increase in understanding that reaches more than 37 points. This improvement indicates that visualization of solar system objects in 3D plays a big role in making it easier for students to understand the concepts of rotation, revolution, planetary characteristics and other astronomical phenomena. Apart from that, the interactive and realistic nature of Augmented Reality can increase students' attention, involvement and learning motivation.

Table 5. N-gain results

| | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Play | 46 | -.33 | 1.00 | .7132 | .33099 |
| NGainPercent | 46 | -33.33 | 100.00 | 71.3198 | 33.09863 |
| Valid N (listwise) | 46 | | | | |

According to Table 4.6, the N-gain values are average *(mean)* a total of 0.713 shows that the use of Augmented Reality assisted Solar System Learning Media provides increased mastery of learner concepts in the very effective category, according to the N-gain effectiveness criterion, namely > 0.70. The average N-gain percentage of 71.32% also strengthens that Augmented Reality-based learning has a significant impact in helping students understand abstract Solar System concepts to become more concrete and easy to visualize. This shows that AR features, such as planetary 3 D objects, simulations of rotational motion and revolution, and orbit visualization, are able to improve learners' engagement and understanding. This research shows that Augmented Reality (AR) is able to bridge the gap between abstract astronomical concepts and students' visual-spatial understanding. Improved concept mastery reflected in high N-gain scores in your studies aligns with literature findings: AR implementation in solar system materials consistently improves learning outcomes and reduces misconceptions through 3D visualization, rotation–revolution simulations, and orbits that students can explore directly [26], [27]. Positive effects of AR on mastery of science concepts, motivation, and scientific thinking skills [28].

AR's conformity with the Independent Curriculum appears in the drive for interpretation of phenomena, scientific literacy, and meaningful learning experiences. Implementation of the Merdeka Curriculum through AR media is reported to improve learning outcomes because AR encourages active involvement, independent exploration and multimodal integration of information [29]. On the other hand, recent systematic studies emphasize that AR supports deep learning building mental models and minimizing cognitive load when studying complex science concepts when designed with directed conceptual strategies (e.g. concept maps) and consistent interfaces [30], [31]. The very high expert validation of content, design and media aspects of your research is consistent with AR design recommendations: commensuracy with the curriculum, precise scientific narrative, intuitive interface and meaningful interactivity. The literature underlines that design consistency and integration of interactive features improve media quality and learning outcomes especially if the 3D object is scientifically accurate and navigation is clear to support inquiry [28], [32]. When learning strategies (e.g. Problem-Based

Learning) are combined with AR in solar system materials, the effects are significant on concept understanding and problem-solving abilities [33], [34]. The high practicality of AR media in your studies is easy to use on smartphones, clear instructions, attractive visuals intersect with the findings of mobile-based AR implementation in the Indonesian school context. National and international studies show that marker-based AR (often developed with Unity) is the most popular type due to its reliability of detection and ease of content integration, while facilitating adoption by teachers and students [35], [36]. This accessibility is important for experiential learning (experiential learning), where students can manipulate representations of celestial bodies and construct conceptual schemes through hands-on exploration [37].

The effectiveness of AR is reflected by the significant improvement of posttest scores and high-category N-gain scores in your study, which is in line with the latest meta-analysis of AR in IPA. Evidence suggests AR has a strong impact on learning outcomes, especially when content, instructional, and technical are optimized, as well as when AR is used to visualize dynamic phenomena that are difficult to explain through text or 2D images [38][39]. Studies applying AR to solar system materials show improved understanding of IPA concepts through pretest–posttest design and N-gain measurements [39], [40]. In terms of pedagogy, AR helps reduce common misconceptions (e.g. planetary order, distance scales, and rotational differences–revolution) because it provides precise visual cues and multimodal interactions [41]. As students can "view" and test the representation of orbit and motion, the concept's exteriorization process becomes stronger, and intrinsic cognitive load decreases. AR interventions combined with concept map strategies were shown to improve mental model formation and optimize cognitive load, accelerating conceptual restructuring from preconception to scientific concept [42], [43]. Nevertheless, AR adoption faces pragmatic challenges. Limited devices, networks, and technical skills of teachers are often obstacles, especially in schools with low digital readiness. National literature highlights the importance of teacher training, usage guidelines, and simple AR design to fit real conditions in the classroom; gradual implementation models and infrastructure support have been found to increase program acceptability and sustainability [44]. Systematic reviews also reminded that the content of ARs is kept scientific precision; non-precise representations actually risk giving rise to new misconceptions, so expert validation and limited trials are important steps [45].

The findings demonstrate that AR-based learning media significantly enhance students' conceptual understanding of Solar System topics by providing interactive 3D representations that reduce cognitive load and support spatial reasoning [46], [47]. These results align with previous studies reporting that AR facilitates conceptual change and minimizes misconceptions in science learning [37], [48]. Overall, recent evidence supports that AR media for Solar Systems when developed in harmony with curricula, expert validation, and integrated with exploration-based pedagogical strategies have a major impact on students' concept mastery, motivation, and scientific thinking skills [49]. Your research stands in line with these trends, confirming that the quality of design, clarity of instruction, and readiness of the school ecosystem are determining factors in the success of AR implementation in science learning [50]. Compared with earlier AR studies, this research contributes new insights by integrating curriculum alignment, systematic development evaluation, and empirical effectiveness testing within a single framework. The results suggest that AR learning media not only improve learning outcomes but also support the pedagogical goals of inquiry-based science education. Nevertheless, limitations include the relatively small sample size and the absence of a control group. Future studies should employ experimental designs with larger samples and investigate long-term retention effects. Despite these positive outcomes, several limitations should be acknowledged. The study involved a single school and a limited number of participants, which may restrict generalizability. Additionally, the effectiveness analysis relied primarily on cognitive outcomes, without extensive examination of long-term retention or affective factors. Future research should involve larger samples, experimental designs with control groups, and investigations into long-term learning retention and teacher readiness for AR integration.

## 4. CONCLUSION

Based on the research results obtained, the conclusions of this research are as follows. 1) AR-assisted learning media on solar system materials to improve concept mastery have been successfully developed and declared to be highly valid (100%), highly practical (96.82%), and highly effective (N-gain 0.71). 2) AR is able to increase students' mastery of concepts, motivation to learn, and support the achievements of the Independent Curriculum. 3) The main obstacle is the limited technical tools and skills of teachers, so training support is needed. This study concludes that AR-assisted Solar System learning media developed using the 4D model are highly valid, practical, and effective in improving students' conceptual mastery. The findings contribute new empirical evidence supporting the instructional value of AR for abstract science topics and offer practical implications for teachers seeking to integrate innovative digital media into curriculum-oriented learning. From a theoretical perspective, this study reinforces the role of immersive visualization in facilitating conceptual change. Practically, it highlights the importance of teacher training and infrastructure support to ensure sustainable AR implementation in schools.

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## AUTHOR CONTRIBUTIONS

Dwi Anggi Ramadhani was responsible for the research design, data collection, data analysis, and manuscript preparation. Ismet, as the first supervisor, contributed to conceptual development, research methodology guidance, and critical review of the manuscript. Ketang Wiyono, as the second supervisor, provided academic supervision, validation of research procedures, and revisions to improve the quality and clarity of the manuscript. All authors have read and approved the final version of the manuscript.

## CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

## USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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