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STEM-PjBL Based AR to Enhance Students' Conceptual Understanding and Digital Literacy on Solar System Concept

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Solar system concept;
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Abstract

The Solar System is an abstract and difficult concept for students to understand. On the other hand, conceptual understanding and digital literacy are competencies that students must have in the 21st century. The purpose of this study was developed and analyse STEM-PjBL based Augmented Reality for enhancing students' conceptual understanding and digital literacy in Solar System concept. Quasi-experimental research with pretest and post-test group design was utilized in order to answer the research questions in this study. The results of the study showed that STEM-PjBL based AR media were effective in improving students' conceptual understanding with an N-gain score in the experimental class of 0.71 (high criteria) compared to the control class of 0.41 (moderate criteria). The highest conceptual understanding indicators were in inferring and comparing. STEM-PjBL-based AR media was effective in improving students' digital literacy with an N-gain score in the experimental class of 0.57 (moderate criteria) compared to the control class of 0.22 (low criteria). The highest digital literacy indicators are in communication, content creation, and problem solving. So, STEM-PjBL based AR is effective to enhance students' conceptual understanding and digital literacy on solar system concept.

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Introduction

In this era of industrial revolution 4.0, the ability to adapt and use technology by students as Gen Alpha is very necessary (Lase, 2019). The abilities that support the industrial revolution 4.0 and students' 21st century skills are scientific literacy (Li & Guo, 2021), information literacy (Istikomah et al., 2021), and digital literacy (Rahmat et al., 2024; Rosali & Suryadi, 2021). Digital literacy is a person's ability to use computer devices to access various information in digital spaces (Martínez-Bravo et al., 2022) or skills in using digital media responsibly (Audrin & Audrin, 2022; Tseng et al., 2022). In 2024, the Ministry of Communication and Information stated that Indonesia's digital literacy index was at 3.78 (assessment scale from 0-5). Several previous studies show that students' digital literacy is still low (Peng & Yu, 2022; Wijaya et al., 2021).

The low level of student digital literacy is caused by several factors, including a lack of aspects of knowledge, behavior and experience in accessing digital spaces. The knowledge aspect relates to the use of a Personal Computer (PC), internet, social media, and privacy settings on social media. The behavioral aspect is related to how to control information obtained between fellow users on social media. The experiential aspect is related to students' basic experiences when interacting using social media (Mawarni et al., 2021). Apart from digital literacy skills, understanding concepts is also one of the abilities that supports the industrial revolution 4.0 and 21st century skills (Giawa et al., 2022). Understanding this concept is the root ability of other abilities and skills. In other words, understanding concepts is a key aspect of learning (Giawa et al., 2022). Understanding concepts is a process of gaining in-depth knowledge of information about an object. The students have a good understanding of concepts if they are able to explain the concepts they have learned in their own language and can apply them in everyday life (Kholid et al., 2021).

Understanding the concepts that are the basis of these other abilities will also influence students' problem solving. The results of the Program for International Student Assessment (PISA) survey in 2022 show that the average score of Indonesian students in the field of science is 383 with the Organization for Economic Co-operation and Development (OECD) average score being 485, 102 points different from the score global. This shows that students' understanding of concepts in the field of Natural Sciences is still not optimal. Solving this problem is related to science concepts that students must understand. Understanding concepts in the science context means students' ability to understand the relationship between concepts and each other so that they can be applied to solve problems. Several previous studies also show that junior high school students' understanding of concepts is still low (Dewi & Komang, 2023).

Observation results at SMP Negeri 27 Semarang show that students' understanding of digital literacy in science learning is still not optimal. This can be seen from the results of students' work in solving questions according to indicators of understanding the concept during the exam. Only 30% of the total students in one class were able to do science questions correctly, both questions and reasons on the Two-Tier Multiple Choice (TTMC) question type, the other 70% did not do both questions and reasons correctly. The learning media used in science learning only uses textbooks from schools, material on the Solar System pages 187-231. The Solar System material in the textbook is visualized in 2 dimensions (2D), not yet 3 dimensions (3D). Teachers have never implemented Augmented Reality (AR) and applied the Science, Technology, Engineering, Mathematic-Project based Learning (STEM-PjBL) approach in science learning explicitly. The learning process at SMP Negeri 27 Semarang also rarely uses learning media in the form of Android-based applications. In fact, Android-based applications, especially AR learning media based on STEM-PjBL, can support the industrial revolution 4.0 and 21st century skills.

Teknowijoyo (2020) states that 92% of future jobs require good digital literacy. STEM is also a current research trend at the global level (Widiyatmoko et al., 2023; Zhan et al., 2022). The Science component in STEM is related to knowledge or understanding of certain materials in science learning (Widiyatmoko et al., 2024). STEM-PjBL based AR learning media has also become an educational trend in the last decade (Simamora, 2024). Several previous studies stated that learning media with a STEM-PjBL approach can improve conceptual understanding (Ate et al., 2022) and digital literacy (Surur et al., 2023). AR media can improve conceptual understanding (Hendracipta et al., 2021; Uno, 2024), and digital literacy (Hidayat et al., 2024).

No previous research has developed and researched STEM-PjBL-based AR learning media to improve conceptual understanding and digital literacy for junior high school students, especially Solar System material. The Solar System is abstract material and difficult to understand (Putra et al., 2021). Students need to understand the basic concepts of the Solar System, and this can be achieved through 3D AR, STEM-based materials, and projects with a PjBL approach. The current Curriculum also strongly supports the role of technology in learning (Ningsih & Sari, 2024). Therefore, research into the development of AR learning media based on STEM-PjBL to enhance students' conceptual understanding and digital literacy on Solar System material is very important to carry out. The aim of this research is to develop and analyze the effectiveness of STEM-PjBL based AR media to enhance students' conceptual understanding and digital literacy in Solar System concept.

Method

The research was quasi-experimental design with 32 students as a sample. A pretest was carried out to determine students' conceptual understanding and digital literacy. After carrying out the pretest, the experimental class was given treatment by applying STEM-PjBL based AR. Meanwhile, the control class was given learning using PowerPoint learning media assisted by student textbooks. After the learning process, a posttest was carried out for both classes. The research implementation process can be seen in Figure 1.

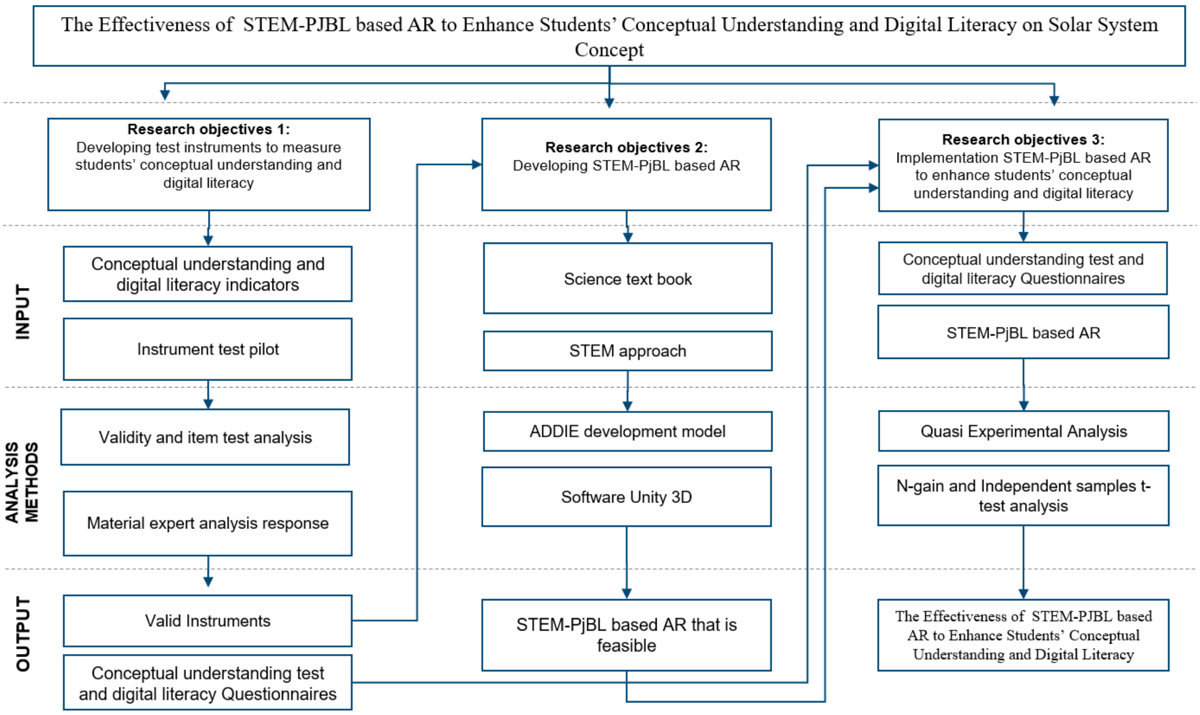

Figure 1. Research Stages

Figure 1 shows the details of the research stages to enhance students' conceptual understanding and digital literacy in Solar System concept. This study consisted of three stages, namely (1) developing a test instrument to measure student's conceptual understanding and digital literacy, (2) developing STEM-PjBL based AR, and (3) implementing STEM-PjBL based AR to enhance students' conceptual understanding and digital literacy. The sample for this research was students from middle school class VII G (experimental class) and class VII H (control class) at SMP Negeri 27 Semarang.

STEM-PjBL based AR media was analyzed for feasibility from media and material aspects first by media and material experts. Students' conceptual understanding and digital literacy were measured through pretest and posttest. The concept understanding instrument consists of 20 questions with TTMC type questions with indicators of conceptual understanding from Anderson et al. (2001), including interpreting, exemplifying, classifying, inferring, explaining, and comparing. The question numbers for each indicator and their explanations are presented in Table 1.

Table 1. Conceptual Understanding Indicators

Conceptual Understanding Indicator	Details	Number of Questions
Interpreting	Students can interpret one form of information into another form of information, for example, images into sentences or sentences into images.	1, 10, 11, 20
Exemplifying	Students can give examples on the Solar System material, which can be in the form of 1) general concepts and 2) identifying specific characteristics.	2, 8, 17
Classifying	Students group the types of planets in the Solar System	5, 6, 18
Inferring	Students are able to make conclusions based on the information presented.	3, 12, 13, 15
Explaining	Students are able to explain the occurrence of a phenomenon or cause and effect between parts.	7, 9, 14
Comparing	Students are able to compare information received or show similarities and differences between two or more objects.	4, 16, 19

Meanwhile, the digital literacy instrument consists of 15 statements with digital literacy indicators including 1) information, 2) communication, 3) content creation, 4) safety, and 5) problem solving (Ferrari, 2013).

Table 2. Digital literacy indicators (adapted from Ferrari, 2013)

Digital Literacy Indicators	Details	Number of Questions
Information	Students can analyze Solar System information through digital technology.	1, 2, 3, 4
Communication	Students can connect online and are able to collaborate through digital devices in creating science content on the Solar System material.	5, 6, 7
Content creation	Students can create and develop science content on the Solar System material.	8, 9, 10
Safety	Students can protect personal data when creating science content on the Solar System	11, 12
Problem solving	Students can solve problems with digital infrastructure	13, 14, 15

The effectiveness of STEM-PjBL based AR media can be seen from increasing students' conceptual understanding and digital literacy for the Solar System concept at the implementation stage using the N-gain formula, namely:

$$\langle g \rangle = \frac{(Sf)-(Si)}{100\%-(Si)}$$

Information:

$\langle g \rangle$: N-gain factor

(S_i) : Pretest mean score (%)

(S_f) : Posttest mean score (%)

The N-gain factor criteria can be seen in Table 3.

Table 3. N-Gain Factor Interval Criteria

Interval	Criteria
$0.0 < \langle g \rangle \leq 0.3$	Low
$0.3 < \langle g \rangle \leq 0.7$	Medium
$0.7 < \langle g \rangle \leq 1.00$	High

Table 3 shows the N-Gain criteria. STEM-PjBL based AR media is said to be effective in increasing conceptual understanding and digital literacy of junior high school students if an N-Gain of at least 0.3 is obtained with medium criteria.

Results and Discussion

STEM-PjBL based AR is an android-based learning media that can be used by teachers and students in STEM-based science learning in the classroom, especially solar system concept. STEM-PjBL based AR has features: (1) main page, (2) explore STEM, (3) project-based STEM-PjBL, (5) Scan AR, and (6) quiz. The first feature is the introduction. This feature explains what the STEM-PjBL based AR learning media is like including learning outcomes and learning objective flow. Learning outcomes include students elaborating their understanding of the relative position of the earth, moon and sun, the solar system, the structure of the earth's layers to explain natural phenomena that occur in disaster mitigation. The learning objective flow includes, 1) Students can describe celestial bodies, 2) Students can describe the effects of the movement of the earth and celestial bodies on natural phenomena on earth, 3) Students can describe natural phenomena such as lunar and solar eclipses, 4) Students can explain the structure and role of the sun in everyday life, and students can create projects related to the Solar System.

The second feature is the explore STEM feature. This feature is related to the integration of STEM elements in the material. The explore science feature contains science facts and/or student observations of the given science problems (materials in the form of: a glimpse of the Solar System, other celestial bodies, the rotation and revolution of the earth, and solar and lunar eclipses). The delivery of the material can be in the form of text and images. The explore science feature is presented in Figure 2.

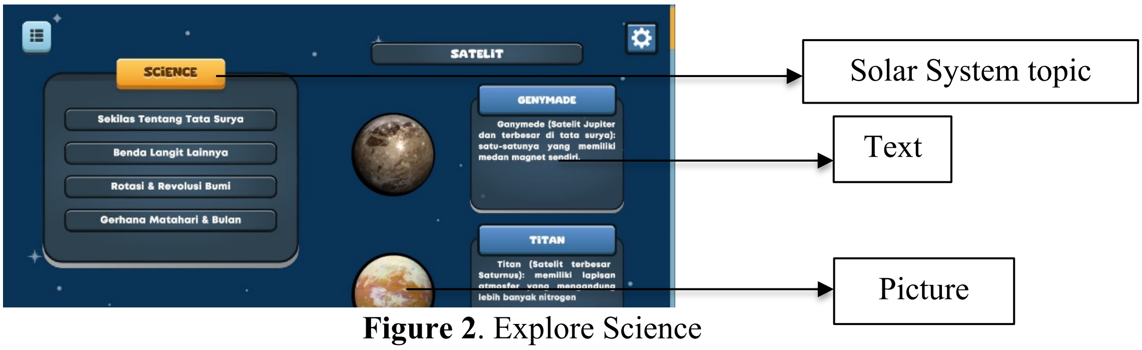

Figure 2. Explore Science

The Explore Technology feature contains the use of student gadgets in searching for literature or new knowledge on the material given. The material is in the form of videos with YouTube references regarding observations with telescopes, comparisons of planet sizes, and the launch of Indonesian satellites. With these videos, students can understand that there is technology that can show celestial objects that cannot be reached by the human eye alone, understand the size of each planet including its distance from the Sun as a basis for understanding to create a miniature model project of the Solar System, and the process of launching an Indonesian satellite (Figure 3).

Figure 3. Explore Technology

The Explore Engineering feature contains techniques or ways of thinking of students towards the material given (in the form of students' thinking processes towards the material or videos given in the Explore Science and Explore Technology). The Explore Mathematics feature contains calculation formulas according to the material in the form of distances between planets and the sun which are visualized with real images and distances (Figure 5).

Figure 4. Explore Technology

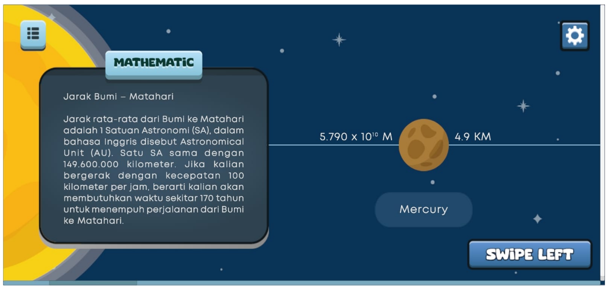

Figure 5. Explore Mathematic

The next feature is the project feature which contains projects that will be carried out by students with PjBL-STEM syntax (Figure 6). This project leads to the creation of a miniature model of the Solar System by students in groups. PjBL syntax includes: starting with essential questions, making a project plan, making a schedule, monitoring students and project progress, testing and assessing results, and evaluating experiences. The PjBL syntax in learning integrates each STEM component, namely Science, Technology, Engineering, and Mathematics. Examples of essential questions that will be asked by the teacher are, "how can we see the planets in the Solar System from this great distance?" or "how far is the distance between the planets and our Solar System? Can you imagine?". These essential questions are the stimulus for students in creating PjBL-STEM-based projects, such as miniature planets and the Solar System. Students and teachers then make a schedule to complete the project and monitor the progress of the project being carried out, followed by testing the feasibility of the project, assessing, and evaluating it.

Figure 6. Project Based STEM-PjBL

The projects made by students in the experimental and control classes are the same project, namely a miniature model of the Solar System. The miniature contains the Sun as the center of the Solar System and 8 planets in it according to their respective orbits. The creation of the project is free from tools and materials, work steps, to any decorations. Students are free to be creative with their respective groups according to the design and timeline that has been made. Examples of students' projects are presented in Figure 7.

Figure 7. Students' project, control class (left) and experimental class (right)

Figure 7 are examples of miniature projects of the Solar System model that have been made by students in the experimental and control classes. Students in the control class made miniature models of the Solar System with sizes that were less considered. For example, in the picture, the size of the Sun with the size of the planet Jupiter is almost the same because Jupiter is the largest planet. Some planets are also placed carelessly, not in the order and orbit of each planet. Some colors also do not match the colors of the planets. Compared to the experimental class, students are more organized in making projects in terms of size, color, and distance between each planet. The planets are also in their respective orbits. Students in the experimental class have a better understanding of the concept of the Solar System compared to the control class. Examples of students' project designs in the experimental and control classes are presented in Figure 8.

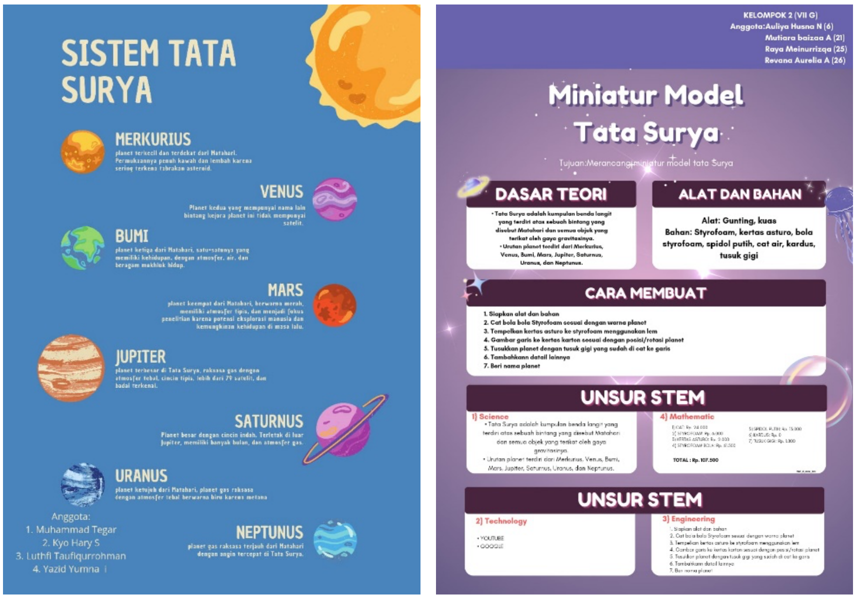

Figure 8. Students' Project Designs, Control Class (Left) and Experimental Class (Right)

Figure 8 is an example of a digital poster from students in both the experimental and control classes. Students in the experimental class were able to create a digital poster of a miniature model project design for the Solar System sequentially starting from the basic theory, tools and materials, how to make it, to the analysis of STEM elements. The STEM elements analyzed include aspects of science, technology, engineering, and mathematics. Some students in the control class were able to create posters according to the teacher's instructions, but most were incomplete. Students in the control class only mentioned the planets with their characteristics, without explaining the design of the miniature model project for the Solar System that would be created.

The next feature is Scan AR. Scan AR contains marker scans or markers by students such as 8 planets in the Solar System, the rotation and revolution of the Earth, and the structure of the Sun. Scan AR will allow students to study Solar System material with 3D visuals, so that something that was previously considered abstract becomes real and easier to understand. The 8 planets in the Solar System include Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. The 3D visuals of the 8 planets are adjusted to the color, structure, and size of each planet. The rotation and revolution of the Earth are also visualized in 3D, the Earth appears to be rotating in its orbit (rotation) while moving around the Sun (revolution). The 3D structure of the Sun is in the form of the appearance of the Sun to the core. In addition to 3D visuals, brief information about these topics is also displayed in this feature. One example of the Scan AR feature is presented in Figure 9.

Figure 9. Scan AR

The next feature is a quiz. The quiz contains practice questions related to the material that has been studied and understood by students in the previous features. The quiz contains 5 practice questions on the Solar System concept. Students will know whether the answer is right or wrong so that it can be used for further evaluation. Students can also work on the questions again in this feature. The features of STEM-PjBL-based AR learning media will enable students to understand the concept of the Solar System well. STEM-PjBL-based AR learning media is presented in the form of an application, so students must download it first. However, this application is very easy to use and can be used whenever students want to learn. The integration of STEM, PjBL, and AR can make learning for students more interesting and meaningful.

The effectiveness of students' conceptual understanding was measured using pretest and posttest questions with 20 multiple choice questions. The enhance in conceptual understanding of students in the experimental class and control class is calculated using N-gain which is presented in Table 4.

Table 4. Data on Increasing Students' Conceptual Understanding in The Experimental and Control Class

Class	Pretest average	Posttest average	N-gain	Criteria
Experiment	50	86	0.71	High
Control	49	70	0.41	Medium

Table 4 shows that there is a difference in the average pretest and posttest scores of students' conceptual understanding, which means there is a difference before and after implementing STEM-PjBL-based AR media in the experimental class and PPT media in the control class. The average pretest and posttest scores in the experimental class were 50 and 86 respectively, obtaining an N-gain value of 0.71 with high criteria. The average pretest and posttest scores in the control class were 49 and 70 respectively, obtaining an N-gain value of 0.41 with moderate criteria. The N-gain score results ≥ 0.3 in the experimental class indicate that STEM-PjBL-based AR media is effective in improving students' conceptual understanding. The N-gain results per conceptual understanding indicator are presented in Table 5.

Table 5. N-Gain of Students' Conceptual Understanding for Each Indicator

No.	Indicators	N-gain			
		Experiment	Criteria	Control	Criteria
1	Interpreting	0.67	Medium	0.47	Low
2	Exemplifying	0.78	High	0.36	Low
3	Inferring	0.79	High	0.53	Low
4	Comparing	0.79	High	0.68	Low
5	Classifying	0.61	Medium	0.27	Low
6	Explaining	0.60	Medium	0.39	Low

Table 5 shows the N-gain per indicator of students' conceptual understanding. The data shows that there is an increase in conceptual understanding scores for each indicator of students' conceptual understanding in the experimental and control classes. The increase in conceptual understanding scores in the experimental class is higher than in the control class. This is because there is a different treatment between the two. The experimental class uses AR STEM-PjBL media so that it can help foster students' conceptual understanding. Furthermore, a t-test was conducted to determine whether there was a significant difference in the increase in conceptual understanding in the experimental and control classes. The results of the t-test are presented in Table 6.

Table 6. T-Test of Students' Conceptual Understanding

Class	Variance	t_{count}	t_{table}	Information
Experiment	151.0071	5.2722	2.0025	Ha's accepted
Control	123.1373			

Table 5 shows the results of the t-test of students' conceptual understanding in the experimental and control classes. The results of the analysis obtained data t count 5.2722 ≥ t table 2.0025, so there is a significant difference in the increase in students' conceptual understanding in the experimental class using STEM-PjBL-based AR media with the control class using PPT media. This significant difference indicates that STEM-PjBL-based AR media is effective in improving students' conceptual understanding of the Solar System concept.

The results of the effectiveness of STEM-PjBL-based AR media on students' digital literacy in the Solar System material were obtained from the analysis of the results of the pretest and posttest of digital literacy on each indicator that had been filled in by students. STEM-PjBL-based AR media can be said to be effective in improving students' digital literacy if the N-gain score is ≥ 0.3. The test of the effectiveness of the media on digital literacy was carried out in class VII G as the experimental class and class VII H as the control class. The non-test instrument in the form of a digital literacy scale contains 15 statements with 5 dimensions of digital literacy, namely the dimensions of information, communication, content creation, safety, and problem solving. The results of the analysis of the pretest and posttest of digital literacy in the experimental and control classes are presented in Table 7.

Table 7. Students' Digital Literacy

Class	Pretest Average	Posttest Average	N-gain	Criteria
Experiment	64	85	0.57	Medium
Control	66	74	0.22	Low

Table 7 shows that there is a difference in the average pretest and posttest scores of students' digital literacy, which means there is a difference before and after implementing STEM-PjBL-based AR media in the experimental class and PPT media in the control class. The average pretest and posttest scores in the experimental class were 64 and 85 respectively, obtaining an N-gain value of 0.57 with moderate criteria. The average pretest and posttest scores in the control class were 66 and 74 respectively, obtaining an N-gain value of 0.22 with low criteria. The N-gain score results ≥ 0.3 in the experimental class indicate that STEM-PjBL-based AR media is effective in improving students' digital literacy. The N-gain results per digital literacy indicator are presented in Table 8.

Table 8. N-Gain of Students' Digital Literacy for Each Dimention

No.	Dimentions	N-gain			
		Experiment	Criteria	Control	Criteria
1	Information	0.55	Medium	0.28	Low
2	Communication	0.60	Medium	0.21	Low
3	Content creation	0.60	Medium	0.27	Low
4	Safety	0.52	Medium	0.19	Low
5	Problem solving	0.60	Medium	0.22	Low

Table 8 shows the N-gain per indicator of student digital literacy. The data shows that there is an increase in digital literacy scores for each indicator of student digital literacy in the experimental and control classes. The increase in digital literacy scores in the experimental class is higher than in the control class. This is because there is a different treatment between the two. The experimental class uses AR STEM-PjBL media so that it can help foster students' digital literacy. Furthermore, a t-test was conducted to determine whether there was a significant difference in increasing digital literacy in the experimental and control classes. The testing criteria for the t-test are if $t_{count} < t_{table}$ then Ho is accepted, while if $t_{count} \geq t_{table}$ then Ha is accepted. The results of the t-test are presented in Table 9.

Table 9. t-Test of Students' Digital Literacy

Class	Variance	t_{count}	t_{table}	Information
Experiment	72.2262	7.0795	2.0025	Ha's accepted
Control	41.0366			

Table 9 shows the results of the t-test of students' digital literacy in the experimental and control classes. The results of the analysis obtained t-test data 7.0795 ≥ t-table 2.0025, so Ha is accepted, so it can be seen that there is a significant difference in increasing students' digital literacy in the experimental class using STEM-PjBL-based AR media with the control class using PPT media. This significant difference indicates that STEM-PjBL-based AR media is effective in improving students' digital literacy in the Solar System concept. The integration of STEM components in the Solar System material can improve students' conceptual understanding. This is in line with previous research, Sandi (2021) which stated that there is an influence of learning with the STEM approach on students' conceptual understanding of electroplating material with high N-gain criteria. (Abdi et al., 2021) in their research also stated that the application of the STEM approach can improve the understanding of physics concepts. Similar studies have also examined that STEM has an influence on improving students' conceptual understanding of energy material (Ozkan & Umdu Topsakal, 2021), hydrolysis (Laliyo et al., 2022), fluid dynamics (Aldi et al., 2022), and temperature and heat (Rochman et al., 2024). The STEM approach integrates science, technology, engineering, and mathematics in one learning framework. This will help students learn concepts from various interrelated sciences and apply them in real contexts in the form of projects (Markula & Aksela, 2022).

The integration of STEM components in the Solar System material can also improve students' digital literacy (Alyspa et al., 2022; Maisarah et al., 2022; Rahayu et al., 2022). With the STEM approach, students will work together in designing STEM-based projects, namely miniature models of the Solar System through a digital platform, in this case the Canva platform. Students can share data and discuss through online forums on Canva. This can hone students' ability to communicate and collaborate digitally. The STEM approach also encourages students to be able to search for and use digital resources such as educational videos, online articles, online mass media and other references in project design. This can broaden students' knowledge and improve skills in finding and evaluating digital information on the internet (Fauzziah et al., 2024).

The AR Scan feature in STEM-PjBL-based AR media includes 8 planets in the Solar System consisting of Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, the rotation and revolution of the Earth, and the structure of the Sun. Zaid et al. (2022) in their research stated that learning media with AR can improve the quality of science learning, including students' conceptual understanding. AR is effective in helping students achieve conceptual understanding, both abstract and complex concepts. Other studies also state that AR can improve conceptual understanding in food (Pujiastuti & Haryadi, 2023), taxonomy (Marques et al., 2022), and molecular geometry (Abdinejad et al., 2020).

AR allows students to see 3D representations of abstract or difficult-to-understand concepts, such as the Solar System. This visualization makes the concept more real and easier to understand. AR can also improve students' digital literacy. (Soutthaboualy et al., 2021) in their research stated that the development of AR technology can improve digital literacy. In running AR, students need to download and operate the AR application, and integrate hardware such as smartphones. This experience teaches students how to use various types of digital devices and applications. Using AR often involves problem solving, such as resolving application errors, adjusting device settings, or interpreting digital data. This experience teaches students how to think critically and creatively in dealing with technological challenges. The use of AR often involves access to digital resources and information, such as online databases, videos, images, and text. Through AR, students can learn how to search for, evaluate, and use digital information effectively.

Conclusion

The characteristics of STEM-PjBL-based AR media include STEM-based Solar System material, 3D visualization of the Solar System through AR Scan, STEM-PjBL-based projects, and Solar System practice questions through quizzes. 3. AR media based on STEM-PjBL effectively improves students' conceptual understanding of the Solar System material with an

N-gain of 0.71 (high criteria) in the experimental class compared to the control class of 0.41 (moderate criteria). The highest conceptual understanding indicators are in the inferring and comparing indicators. 4. AR media based on STEM-PjBL effectively improves students' digital literacy in the Solar System material with an N-gain of 0.57 (moderate criteria) in the experimental class compared to the control class of 0.22 (low criteria). The highest digital literacy indicators are in communication, content creation, and problem solving. So, it concluded that STEM-PjBL based AR is effective to enhance students' conceptual understanding and digital literacy on solar system concept.

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