

Development of an Immersive Educational Tool for Solar System Topics

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Abstract

The study of the solar system is a critical component of science education, offering students a deeper understanding of natural phenomena. However, traditional teaching methods often fall short in effectively engaging students and fostering comprehensive understanding. This study aims to develop an immersive learning tool utilizing metaverse technology, following the ADDIE development model. The resulting product includes two virtual spaces designed for exploration and learning by students.

The evaluation process involved both Alpha and Beta Testing. Alpha Testing was conducted with four experts, comprising two specialists in AR, VR, and XR media, and two experts in science content. Beta Testing involved a small group of 15 students to assess the usability of the immersive application. The evaluation by media experts rated the learning tool as "highly feasible" for educational purposes, while assessments from science content experts categorized it as "feasible" for instructional use. Usability testing results further classified the application as "excellent" overall.

Keywords: ADDIE, Alpha Beta Testing, Immersive Technology, Solar System

Background

Learning about the solar system is an essential component of science education, enhancing students' understanding of natural phenomena and fundamental physics concepts. However, conventional teaching methods often fail to effectively capture students' interest and facilitate deep comprehension (Fitriya et al., 2024). Traditional learning approaches are frequently one-directional, where students passively receive information without active engagement in the learning process. This lack of involvement can lead to decreased motivation, limited participation, and minimal interaction in the classroom (Alessa & Hussein, 2023). Students are often taught to memorize information without truly understanding or critically analyzing it, which negatively impacts their ability to think critically (Hasan, 2021). Furthermore, many conventional methods are unable to meet the diverse learning needs of students (Pires, 2021), thereby restricting opportunities for students to demonstrate their knowledge and skills in more creative ways (Nurutdinova et al., 2016).

In the field of education, innovation plays a crucial role in enhancing the effectiveness of the teaching and learning process. Through innovation, it is expected that students' academic achievements can improve in line with the rapid advancements in technology.



One innovative method to support students' understanding is the integration of technology into learning (Khulaifatuzzahra et al., 2024).

While numerous teaching methods have been introduced, immersive learning is gaining increasing attention as an effective approach. The concept of "immersive" learning refers to an educational experience that actively engages students through multiple senses, such as touch, sight, and hearing, allowing them to directly interact with relevant objects, environments, or situations. Immersive learning has been shown to enhance student engagement and deepen their understanding of the material, as it enables students to experience learning in a more realistic and practical context (Fitrianto & Saif, 2024; Huang et al., 2020).

Previous research conducted in 2023 highlights that the readiness of schools to adopt immersive technology is a critical factor in ensuring its successful implementation in the learning process. The findings provide an overview of the general preparedness level of educational institutions collaborating with SEAMOLEC to integrate immersive technology into education. The results indicate that these institutions fall under the category of "READY" to adopt this technology, albeit with several areas requiring improvement. One notable area for enhancement is the availability of immersive content, which remains limited and necessitates further development for effective use in learning.

For the implementation of this study, a model school—SMK Kristen Immanuel Pontianak, a partner of SEAMOLEC—was selected. A Focus Group Discussion (FGD) was conducted with teachers from SMK Kristen Immanuel Pontianak to collaboratively develop an immersive learning content prototype. Subsequent phases will involve Alpha and Beta testing to evaluate the content's effectiveness and usability. The contributions of immersive technology in educational area demonstrate that it is a powerful tool to use in classrooms because it allows many interactive visual forms of learning especially for fundamental concepts that are not easy to teach due to their content being distant from students' everyday reality. Therefore, the use of tools is essential for a better understanding among students and serves as a good methodological alternative for teaching the initial concepts of the Solar System. (Siqueira, P. H., 2019)

Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR), collectively referred to as Extended Reality (XR), have unlocked new opportunities in education by creating immersive and interactive learning experiences. According to Huang et al. (2020), the integration of XR technology in education not only enhances student engagement but also allows for deeper interaction with learning content. In this context, the metaverse serves as a virtual space where students can explore complex concepts, such as the solar system, in a more engaging and comprehensive manner.

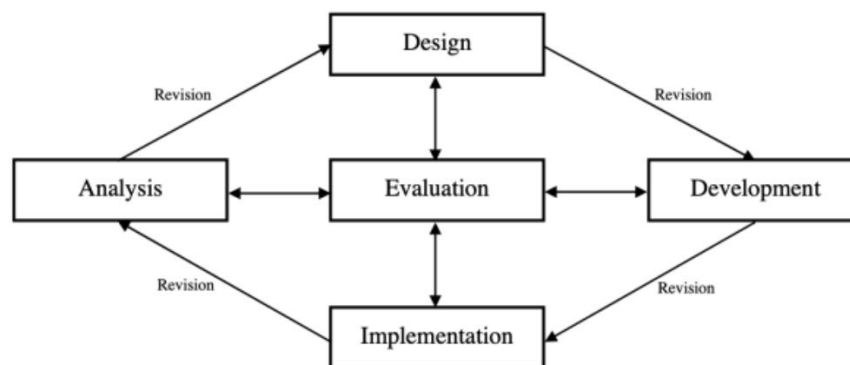
The combination of AR, VR, and MR within the metaverse not only enhances student engagement but also supports effective experiential learning. Research indicates that the use of XR technology in education fosters a more interactive and immersive learning process, which is particularly crucial in the rapidly evolving context of remote learning triggered by the COVID-19 pandemic (Rossi et al., 2023). The metaverse presents opportunities to create more dynamic and engaging learning environments, allowing students to participate in deep simulations and interactions (Latino et al., 2024). This aligns with findings by Erlangga et al. (2024), who emphasized that the metaverse can address educational limitations such as classroom capacity restrictions during the pandemic and physical distance barriers, while also fostering a more interactive and engaging learning environment. By leveraging XR technology within the metaverse, students transition from passive learning to active engagement in the educational process, ultimately improving their motivation and understanding of the subject matter (Zonaphan et al., 2022). Furthermore, several studies have highlighted its benefits in replicating complex scenarios and environments, providing students with practical learning experiences (Al-Qallaf, 2024).

One of the main challenges in developing immersive technology is ensuring that the tools created are not only engaging but also effective in achieving educational objectives. This study aims to develop immersive learning tools using the ADDIE model and to conduct alpha and beta acceptance testing, as outlined in the research of

Amish and Jihan (2024). Alpha testing involves validating the learning tools with media experts and science content specialists, while beta testing includes limited trials with end-users—specifically, 15 students in a classroom setting. The findings of this research are expected to provide new insights into the field of science education and immersive technology, contributing to the development of more effective and impactful learning solutions.

Research Method

The product developed in this study is an immersive learning application based on the metaverse using the ADDIE model. The ADDIE model is widely used in the development of product design, comprising the following stages: (1) Analysis, (2) Design, (3) Development, (4) Implementation, and (5) Evaluation (Fudholi et al., 2020). Figure 1 illustrates the diagram of the ADDIE model.



Pict 1. ADDIE Model

The Analysis phase involves determining the target users of the application, the content to be applied, the individuals who will develop the immersive learning materials, and the media to be used. During this phase, a literature review is conducted, and Focus Group Discussions (FGDs) are held with teachers from SMK Immanuel Pontianak.

Users of this application are students from SMK Immanuel Pontianak, with limited testing involving 15 students from the "Metaverse" extracurricular group. The solar system content was selected based on the results of the FGDs with the teachers. The immersive content will be developed using several software tools according to the needs, including Blender, Unity 3D, Canva, and Spatial IO.

The Design phase is the process of producing the content design, application layout, user interface, system functions, implementation plan, and trial procedures. This phase results in a lesson plan that outlines and describes how the developed application will be used by the users. The lesson plan also includes a storyboard related to the concept of the immersive application that will be developed.

The Development phase is where the data analyzed and designed in the previous phase (Lesson Plan) begins to be developed into an immersive application. The development starts with the creation of 3D objects using Blender software. These objects include the Sun, planets, orbits, and a virtual space environment representing the solar system, designed with a "space" concept. Once the objects are created, they are imported into Unity 3D and then assets are imported into Spatial IO. Further detailed information to be displayed in the virtual space is



designed using Canva. Before moving to the Implementation phase, alpha acceptance testing is conducted, and revisions are made based on expert feedback.

The Implementation phase involves the actual deployment of the immersive solar system learning application with students. In this phase, 15 students are introduced to the immersive application and use it for learning about the solar system. Afterward, students complete a questionnaire to evaluate the usability of the immersive application.

The Evaluation phase is the final stage, which aims to assess the content, materials, and the VR application developed. Evaluation is conducted in three ways: (1) Assessing the usability of the application based on feedback from the 15 students, (2) Expert evaluation of the immersive media by specialists in AR, VR, and XR design, as well as the content by science experts, and (3) Interviews with the development team, including one student and two teachers from SMK Immanuel Pontianak.

The testing methods employed in this study are alpha and beta testing. Alpha testing involves validation through a questionnaire administered to (1) two experts in AR, VR, and XR, and (2) two experts in the field of science content. The media expert validation is conducted through the completion of a survey, and the data obtained are analyzed using a Likert scale with four points. The validation process by the media experts uses a checklist instrument (v) with the following Likert scale: (1) "Strongly Disagree" (score 1), (2) "Disagree" (score 2), (3) "Agree" (score 3), and (4) "Strongly Agree" (score 4). The percentage calculation of the Likert scale feasibility score is calculated using the following formula:

$$Persentase = \frac{\text{Total score}}{\text{Maximum score}} \times 100\%$$

The data is then transformed into percentage intervals with the following criteria: (1) A percentage score of 0%-25% is classified as "Very Unfeasible," (2) A percentage score of 26%-50% is classified as "Unfeasible," (3) A percentage score of 51%-75% is classified as "Feasible," and (4) A percentage score of 76%-100% is classified as "Very Feasible."

A limited trial was conducted after the Solar System learning tool was revised according to the recommendations from media and content experts. The trial was carried out with a small group of 15 students (limited trial). Following the trial, a usability testing questionnaire was distributed, assessing several aspects, including Learnability, Memorability, Efficiency, Errors, and Satisfaction. The measurement scale used was a Likert scale of 1-4. Subsequently, the results of each aspect were averaged and transformed into intervals with the following criteria: (1) An average score of 1.0-1.75 is classified as "Very Poor," (2) An average score of 1.76-2.51 is classified as "Poor," (3) An average score of 2.52-3.27 is classified as "Very Good" (Rusmiani & Hidayati, 2024).

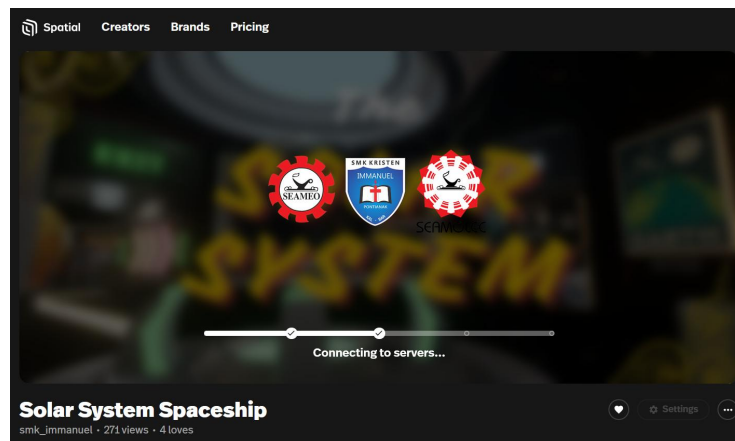
Result and Discussion

Immersive Application on the Solar System Topic

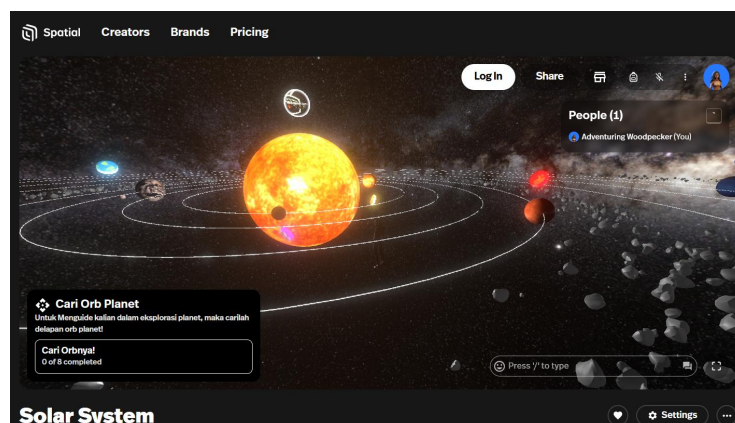
The development results of the immersive application include two virtual rooms for exploration. The first room illustrates the complete arrangement of the solar system. Within this first virtual room, there is a portal leading to the second virtual room. The second virtual room is designed with a "Spacecraft" concept, inside which the solar system objects are individually represented, such as the Sun, planets, and their orbits. Each planet has a detailed explanation provided in its own separate space. The content within each room can be selected for more detailed display. The educational objectives of the developed application are: (1) To ensure that students accurately understand the facts about the Sun as the center of the solar system after exploring the virtual solar system room, and (2) To enable students to identify and explain the main characteristics of each planet in the

solar system, as well as to accurately describe the relationship between the planets and the Sun after navigating through the virtual solar system.

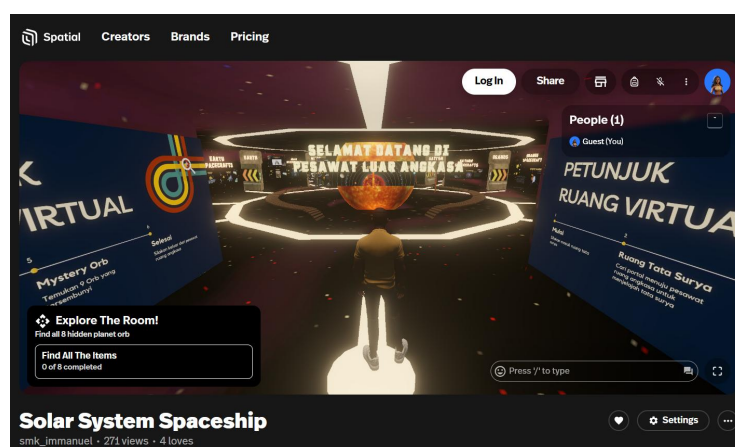
The images below show the results of the successfully developed virtual rooms.



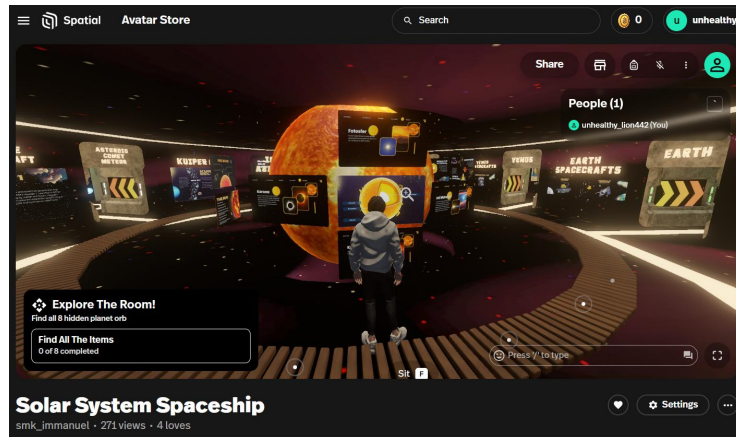
Pict 2. Interface entering the virtual room.



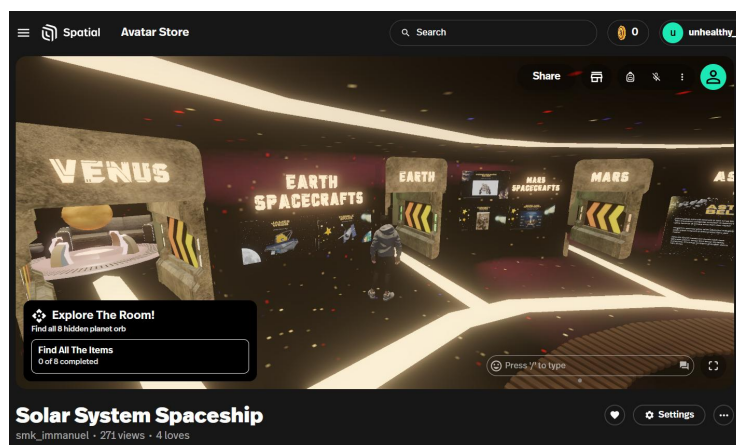
Pict 3. Virtual Room 1 The arrangement of the solar system.



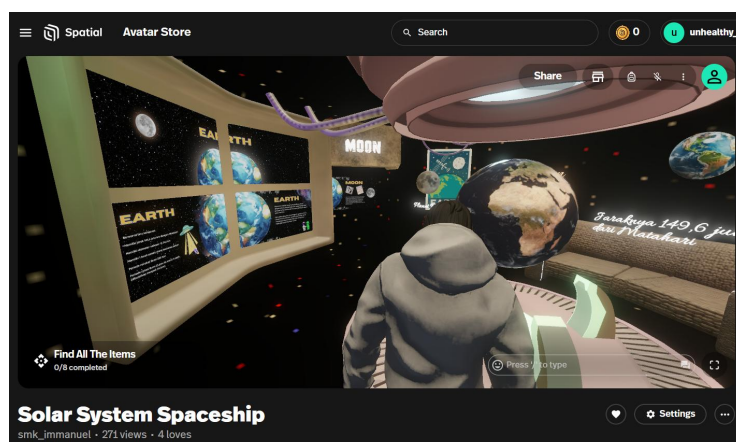
Pict 4. Interface when entering the Solar System Spaceship



Pict 5. Students learn about the Sun.



Pict 6. Students select each planet to enter and study.



Pict 7. Students learn about the earth

Alpha Testing

The results of the alpha testing for AR, VR, and XR media experts were 86% and 89%, indicating the "very feasible" criterion. Table 1 shows the assessments by Expert 1 and Expert 2.

Table 1. Media Expert Assessment Results

Indicator	No	Assessment Aspect	Media Expert 1	Media Expert 2
Interface Design	1	Proportional layout of components (balanced, appropriate, visually comfortable)	4	4
	2	Selection of object colors (harmony, contrast, brightness)	3	4
	3	Selection of environment colors (harmony, contrast, brightness)	3	4
	4	Size of graphic elements (images, 3D objects, icons, buttons) is appropriate and proportional	4	4
	5	Readability of fonts (text)	4	3
	6	Overall graphic quality is good and not blurry	4	4
	7	Free from visual distractions that may divert attention (user focus)	3	4
	8	Consistency of overall visual design (colors, fonts, graphic style)	4	4
Navigation	9	Clear and easy-to-understand usage instructions	4	3
	10	Navigation buttons are easy to recognize and accessible	4	4
Audio	11	Sound quality is clear and easy to hear	2	4
	12	Music support is appropriate for the theme	4	4
Technology Usage	13	Compatibility with various devices:		
		Web Based PC/Laptop	4	4
		VR Headset	4	4
		Smartphone	4	4
	14	Responds to commands without significant latency	4	4
	15	Stability: The educational tool runs smoothly, with no bugs or technical errors	4	4
Gamification	16	Reliability: The educational tool runs smoothly (does not experience crashes or freezes)	4	4
	17	The application offers challenges that effectively help learner	3	2
Total			66	68

Feedback from the media experts:

Media Expert 1's Suggestions: (1) The contrast between the room's environment and the space objects/planets is too overpowering; it would be better to emphasize one element (focus on the main objects). (2) The background envy is too strong and slightly distracts from the main content. (3) Gamification is present, but it

could be made more interactive, informative, and aligned with the subject of the lesson. (4) A narrative explanation should be added to reinforce the content, rather than just background music. Overall, the immersive technology-based learning content is feasible for use with the revisions mentioned.

Media Expert 2's Suggestions: Overall, the design, navigation, audio, and technology usage categories can be considered good and optimal. Conclusion: The tool is feasible for use with revisions according to the suggestions provided.

The evaluation results from two subject matter experts in science for the solar system content yielded the same percentage of 71%, indicating the "Feasible" category. Table 3 shows the evaluation results from the subject matter experts.

Table 2. Assessment Results by Science Matter Experts

<i>Indicator</i>	<i>No</i>	<i>Assessment Aspect</i>	<i>Expert Subject 1</i>	<i>Expert Subject 2</i>
<i>Content Relevance</i>	1	Relevance of content to learning objectives	3	3
	2	Appropriateness of content difficulty level for the target student's ability	3	3
<i>Information Accuracy</i>	3	Accuracy of the material presented (No factual or data errors)	3	3
	4	Content relevance to the latest developments	4	3
<i>Deep of Content</i>	5	Content covers all essential aspects of the topic discussed	2	3
	6	Presentation of material supports comprehensive understanding of the concepts	2	2
	7	Material presentation is structured and systematic, in line with the learning process	3	3
<i>Language</i>	8	The language used in presenting the material is clear and easily understood by students	3	3
<i>Usage Procedure</i>	9	Includes media usage instructions that are easy to understand	2	2
	10	Includes procedural guidelines (structure, learning flow) that can guide students	2	2
<i>Device Effectiveness</i>	11	Procedures are relevant to the material	3	3
	12	This learning tool will help students understand the material more easily	3	3
	13	The tool supports students' independent learning	4	4
Total			37	37

Feedback from Expert 1: (1) Learning Guidelines: The guidelines should not only include technical instructions on how to use the media, but also explain how to teach with it (pedagogical aspects). (2) Time Allocation: The time allocated for each activity should be adjusted according to the activity being performed, as most of it is not aligned (Pre-implementation – Implementation – Post-implementation). (3) Simulation Guidelines: The guidelines for running the solar system simulation in Spatial.io are missing. Please add sufficient detail as a reminder for teachers. Conclusion: Feasible for use with revisions as noted.



Feedback from Expert 2: (1) The Learning Guidelines should not only cover technical aspects but also detail the pedagogical aspects. How can teachers teach the topic using this media? (2) There is a need to standardize the terminology used in both the guidelines and the lesson plan. (3) The Technical Guidelines for new and informative aspects should be made more detailed, such as the instructions for creating avatars. Conclusion: Feasible for use with revisions as noted.

Beta Testing

Beta Testing was conducted by distributing a questionnaire to 15 students who tested the immersive application in terms of usability. Table 4 shows the results of the questionnaire provided.

Table 3. Results of Usability Testing Questionnaire

No	Name	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
1	VN	4	4	4	4	3	4	4	4	4	4	4	4	4
2	GSB	4	3	3	4	4	3	3	3	2	3	4	4	4
3	VEJ	3	4	4	4	4	2	3	4	4	3	4	4	4
4	EJP	4	4	4	4	4	3	4	4	3	4	4	4	4
5	AVS	4	4	3	4	3	4	4	4	4	4	4	4	4
6	FAG	3	4	1	4	2	3	3	3	4	4	4	3	4
7	DJ	3	3	3	4	3	3	4	4	3	3	4	4	4
8	FA	4	4	4	4	4	4	4	4	4	4	4	4	4
9	CQE	3	3	3	4	4	3	4	4	3	3	4	4	3
10	MN	3	3	3	4	4	2	4	4	3	4	4	4	3
11	A	3	3	4	4	4	3	4	4	4	3	4	4	4
12	EA	4	3	4	4	4	3	3	4	3	4	4	4	4
13	SGP	4	4	3	3	4	4	4	4	4	4	4	3	4
14	GS	3	3	3	4	4	4	4	3	4	4	4	3	4
15	DBS	3	4	2	4	3	2	4	4	3	4	4	4	4
Rata-rata		3.4	3.4	3.1	3.8	3.5	3.0	3.6	3.7	3.4	3.6	3.9	3.7	3.8
		3.3		3.7		3.4		3.5		3.8				

P1: Ease of navigation flow within the application (learnability aspect)

P2: Ease of learning the material within the application (learnability aspect)

P3: The application can be used without assistance from others (learnability aspect)

P4: Quick adaptation to navigation direction and features of the application (memorability aspect)

P5: Able to use the application again without relearning (memorability aspect)

P6: Ease of use at any time (efficiency aspect)

P7: Understanding the material becomes easier with the application (efficiency aspect)

P8: Able to learn the material independently using the application (efficiency aspect)

P9: No errors present (errors aspect)

P10: All menus function properly (errors aspect)

P11: The application is interesting to use in learning (satisfaction aspect)

P12: The application enhances enthusiasm for learning (satisfaction aspect)

P13: Would use the application again when needed (satisfaction aspect)

From each aspect, it can be observed that the interval class received scores above 3.28, which falls under the "Very Good" criterion.

The lowest to highest values in sequence are: Learnability: 3.3, Efficiency: 3.4, Errors: 3.5, Memorability: 3.7, and Satisfaction: 3.8

Developer Team Interview

The Developer Team from Sekolah Kristen Immanuel consists of 3 members: (1) the Sun System subject teacher, (2) the ICT teacher, and (3) a student from the computer science department. The teacher provided the concept and idea for the application to be developed, while the student was mainly involved in the technical aspects of creating the immersive application. The development process took approximately 4-5 months.

Initially, during the mentoring sessions with the SEAMOLEC team, the developer team felt very excited and happy about the project, but they also expressed concerns about limited human resources and the complexity of design creation. According to the team, the basic skills required for developing this immersive application include

Blender 3D, Unity, Spatial.io, and Canva. In the early stages of development, the team was still learning how to solve technical challenges and even sought advice from online forums. The development process followed the guidelines and explanations shared earlier.

The main challenges faced by the team were the limited time for completion and the scarcity of human resources. Despite these challenges, the team successfully completed the immersive application according to the target set by the SEAMOLEC team.

The final impression of the development process was one of happiness, satisfaction, and pride in completing the application, despite the difficulties faced along the way. The team provided the following suggestions: (1) For the school to continue the development process, ensuring it does not stop with just one person, providing necessary equipment like laptops, and adding new members to the team. (2) For the SEAMOLEC team to consistently offer training on immersive technology development.

Conclusion and Suggestion

This research resulted in an immersive learning device developed by SMK Immanuel Pontianak, consisting of two virtual spaces. To be used in the learning process, students must first enter the first virtual metaverse space and then proceed to study the second metaverse space (spaceship solar system).

The first virtual metaverse space was specifically created to study the overall structure of the solar system, while the second virtual metaverse space was designed to study each solar system object with a spaceship concept. Overall, despite the limitations in human resources and various challenges in the development of the virtual metaverse learning device, it received a "very feasible" rating from AR VR XR media experts and a "feasible" rating from subject matter experts. Furthermore, usability testing conducted with students resulted in an overall "Very Good" rating. From the brief Q&A session, the immersive device received positive feedback from various parties, including the development team, teachers, and students.

However, several points need to be addressed, including: (1) The concept of the virtual space should be simplified (the number of rooms and the need for multiple entrances and exits adds time, and posters that do not contain educational content). (2) Limited development time. Additional time is required to revise and refine the learning tool. (3) Limited usage time. Virtual space learning was conducted only once per session, and many students were unable to complete the material in the virtual space. The gamification feature was also not explored due to time constraints.

In the future research can be conducted to improve the immersive learning application for the solar system so that it can be used by other schools with similar content. Several points need to be considered, including: (1) The formation of a new development team for future projects through a metaverse extracurricular activity. (2) Providing the development team with adequate devices. (3) If new virtual space content is to be developed, it is recommended that the development concept or idea be discussed with the entire team from the start to achieve all learning objectives. (4) Providing training for teachers and students to continuously develop this technology effectively. The initial limited human resources made development very challenging, but providing basic training

for teachers and students can open up opportunities for continuous development of this technology and ensure it is not limited to one student or group.

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