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Learning Material Selection for Metaverse-Based Mathematics Pedagogy Media Using Multi-Criteria Recommender System

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Abstract: One of the challenges of learning mathematics is making students like the subject to understand the material being taught more efficiently. Therefore, several studies propose the use of gamification elements in the mathematics learning process. Another important consideration in learning mathematics is the accuracy of the subject matter given to students. This study proposes a metaverse-based mathematics pedagogy media (MMPM) equipped with learning material selection (LMS) to adaptively select subject matter according to the level of student knowledge. We use the multi-criteria recommender system (MCRS) to support LMS in providing recommendations for determining the choice of subject matter. The method used to calculate similarity is cosine-based, while the ranking is based on average, worst-case, and aggregate. We built the MMPM system using the unity game engine in the experimental stage. At the same time, the subject matter that becomes the focus of scenario visualization is about beam, cube, prism, and pyramid. The test results show that the LMS system works well in carrying out its duties by adaptively choosing the appropriate subject matter scenarios for students based on their pre-test results. In this study, MCRS-based LMS produces the highest accuracy of 92% for two to three input items and the lowest 90% for four input items.

Keywords: Mathematics, Metaverse, Learning material selection, MCRS.

1. Introduction

Mathematics is one of the essential subjects in school, but many students do not like it. Mathematics is also a beneficial subject matter in the implementation of everyday life [1]. Knowledge and understanding of mathematics subjects are mandatory for students at various levels. But the problem is that conventional learning models commonly used in schools are not optimal in delivering knowledge to students [2]. Learning with traditional methods sometimes makes students bored and less interested in learning [3]. Meanwhile, students need concentration, comfort, and a pleasant learning atmosphere to study mathematics. The goal is to make it easier for them to absorb the material taught by the teacher.

Mathematics learning tools and media continue to develop from time to time [4]. Teachers and researchers continue to create and innovate mathematics learning media to increase students' interest and willingness to learn [5]. Some examples of mathematics learning media that have been developed include multimedia software [6], interactive media [7], E-learning [8], and computer games [9]. Bringing the content of mathematics lessons into media games is an interesting discussion because it can increase students' enthusiasm and enjoyment of the lesson [10]. On the other hand, game-based learning media will be even better if it can provide space for students to interact with teachers and friends. However, the development of learning media also needs to consider the material's suitability with the level of student understanding. With this suitability, each learning media can be expected to increase the efficiency of learning time.

This study proposes mathematics learning media using metaverse technology to answer the challenges and needs of mathematics learning media. Metaverse is a medium with a virtual environment that allows users to connect, communicate, work, learn, play, and transact like in the real world. In addition to improving the immersive learning experience, metaverse also enhances the interactive learning experience for students [11]. We propose virtual reality (VR) based metaverse technology to help students learn math content through a virtual environment that can bring them together with teachers and other students. The use of metaverse-based learning media in education allows students to increase their knowledge of content, motivation, and learning comfort [12]. In this study, the proposed metaverse has a learning material selection (LMS) system to support gamification capabilities in scenario selection based on the choice of subject matter. In this study, we complement the LMS system with the Multi-Criteria Recommender System (MCRS) method to determine recommendations for appropriate mathematics subject matter for students as game players. Furthermore, the system uses these recommendations as a reference in determining the scenario of the subject matter for them. MCRS is a method of generating recommendations based on multi-criteria that can produce more accurate recommendations than conventional methods based on single criteria [13, 14].

In this study, MCRS is responsible for producing recommendations for the choice of subject matter based on the value of several criteria describing the student's understanding level. The LMS system tries to get the value of each criterion based on the students' pre-test results at the beginning of the game. These criteria include the value of student answers, the time it takes, and the value of the solutions for each sub-chapter. In the experimental stage, we use a data set of possible grades for high school mathematics lessons with sub-chapters of building blocks, cubes, prisms, and pyramids. While developing virtual environments and gamification of the metaverse, we use the unity game engine.

In this paper, we divide the discussion of the proposed LMS system into several chapters. First, in the introduction chapter, we explain the background of the research, the problems, and an overview of the proposed solution in the form of an LMS system. The second chapter discusses related work, research gaps, and research contributions. Next, the third chapter discusses the design of metaverse-based mathematical pedagogy of media and the proposed LMS system using MCRS. Our fourth chapter describes the experimental results, while the fifth chapter is the last chapter which contains conclusions and prospects for further research.

2. Related work and contribution of paper

2.1 Mathematics pedagogy media

Several studies have proposed various types of mathematics learning media to increase knowledge transfer to students. One of these studies was conducted by Li Yan and Xingbo. In their paper, they discuss the use of multimedia technology applications in the mathematics learning process in China. One application used in the research's experimental phase is Geometer' Sketchpad. The results showed that using multimedia technology in mathematics learning could support the smooth learning process and potentially improve students' understanding and thinking [6]. In another study, Nurmawati et al. discuss the use of interactive learning as a medium for learning mathematics for elementary school students. The experimental results showed that the group of students who were given the interactive learning treatment got a higher average score than those without interactive learning [7]. Furthermore, Burcu Turan proposed smart board-based mathematics learning media in his paper. The author uses the help of an interactive board visualized in a computer program. Experimental results on students show that using these media can increase student success compared to conventional learning models [15]. Conventional learning is a traditional learning model where the teacher explains the subject matter on the blackboard. At the same time, the students listen to it to understand the lesson delivered by the teacher. The conventional learning process cannot provide visualization of some subject matter to make it easier for students to understand. Therefore, there is a need for learning media to visualize the subject matter well for students, such as this research proposal, where students can understand the subject matter of building a better space with the 3D-based visualization through the VR-based metaverse system proposed by this study.

Several studies have proposed using computer games as a medium for learning mathematics. One of them is done by Hartono et al. through their proposal called the educational mathematics game. The game developed uses a 2-dimensional image and animation format suitable for elementary school students. The test results show that students prefer to learn mathematics through game media. At the same time, the subject matter becomes easier to understand by students than by using conventional learning media [1]. In another study, Sun et al. introduced using digital game-based learning for mathematics. Experiments in this study involved more than one hundred students and several teachers through observation and interviews. The results show that using digital games for students in mathematics has an essential effect on learning activities and mathematics perception [9]. Several studies on mathematics learning media use interactive-based media to single-player computer games with visualizations that still need to be improved. Therefore, this study introduces mathematics learning media using metaverse with visualization of objects and virtual environments based on three dimensions. So, in addition to offering media with a realistic and exciting virtual environment, it also has a multiplayer base that can bring together students and teachers.

2.2 Metaverse-based pedagogy media

The use of metaverse technology as a learning medium is currently an exciting study in several studies. In one study, Park et al. state that the development of metaverse technology requires the support of three components (hardware, software, and contents) and three approaches (user interaction, implementation, and application) [16]. These three components and approaches are the things that become references in the development of metaverse technology for mathematics subject matter as in this study. One of the studies that discuss the use of metaverse technology for learning mathematics was that conducted by Reyes in 2020. The author developed metaverse technology that uses Augmented Reality visualization as a basis. The results of the survey-based descriptive test show that the generated media benefits students' understanding of mathematics subjects [17]. In contrast to previous studies, in this study, we propose the use of a VR-based metaverse as a medium for learning mathematics for high school students. VR can improve cognitive abilities and create a more realistic visual experience for students [18].

Several studies have actually discussed the existence of metaverse-based pedagogy media in terms of content and various technology proposals. One of them is what Siyaev and Jo did in 2021. They introduced a metaverse for learning aircraft maintenance. Their research developed support for neuro-symbolic speech understanding technology to understand user speech when interacting with the metaverse system [19]. In another study, Suzuki et al. discuss the concept of a learning system using metaverse. Their research focuses on developing metaverse-based virtual learning support for an educational system called KOSEN [20]. Several previous studies illustrate that researchers are trying to offer system support to improve the capabilities of the developed metaverse technology. One that has not been discussed is how the metaverse system can choose the appropriate content for the player. Therefore, this study offers an LMS system to support metaverse technology to provide interactive feedback to players on the choice of mathematics subject matter that is suitable for them.

2.3 Scenario selection

One of the exciting discussions of metaverse technology is about gamification [20]. Meanwhile, scenario design is one of the essential components in game development [21]. Therefore, the discussion of scenario selection makes sense in research on the metaverse. Several studies have discussed the concept of scenario selection, one of which was conducted by Pons et al. They propose a scenario control system based on multi-agent for serious games that can choose game scenarios according to the player's behavior reference. Game scenarios can adapt according to the player's developing abilities and skills [22].

In another study, Arif et al. also discussed the scenario selection system developed to support serious game tourism. They use Dynamic Weight Topsis-based Hierarchical Finite State Machine as a scenario selection method. Topsis is one of the decision support system techniques that is used as a selection method with simple computations so that it is possible to support real time capabilities that must be owned by game systems. The scenario selection system automatically selects travel scenarios for players based on their expectations of the desired tourist item [21, 23]. A study conducted by Mihajlovic et al. introduced a scenario control platform that can select scenarios for players through a system called the Interactive Scene Control Environment (SCE). Their research also describes the development of interactive control scenarios in regulating the placement and behavior of objects to then be inserted into the scene [24].

In contrast to several previous studies, in this study, we propose a scenario selection system in learning media based on a metaverse system called learning material selection. Learning materials are selected based on each student's level of knowledge as a metaverse user. Furthermore, the selected learning material is visualized in a learning scenario designed and provided by the system.

2.4 Paper contribution

Based on some of the literature discussed, research on metaverse-based learning media is

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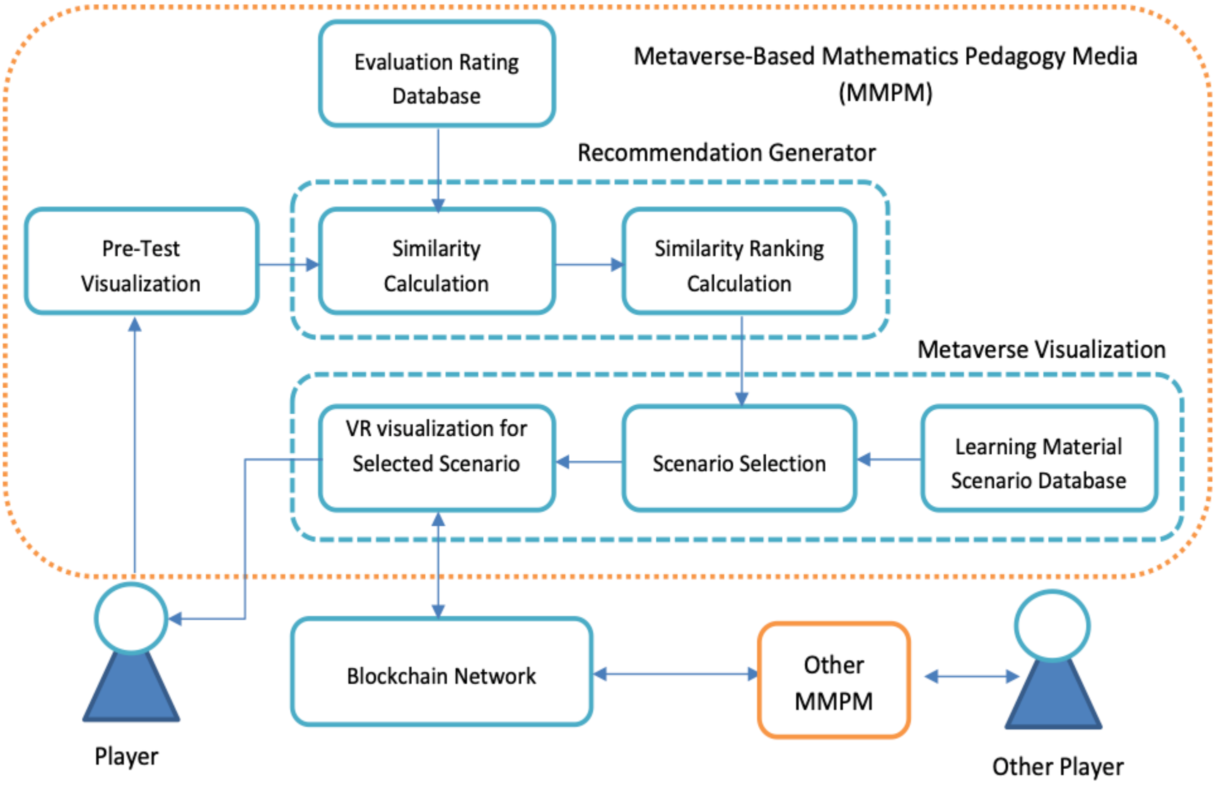

Figure. 1 Proposed system

challenging and exciting. In addition, it turns out that there are still areas of study that need to be addressed and developed to improve the metaverse system's ability to transfer knowledge to its users. In this study, we are motivated to build metaverse-based mathematics learning media that can choose the appropriate subject matter for students so that the knowledge transfer process can run more effectively and on target. This research also has several contributions that are offered as follows:

- In this study, we offer metaverse-based mathematics learning media model equipped with a learning material selection (LMS) system to select subject matter according to the player's knowledge.
- This study uses MCRS to generate recommendations to get the most recommended ranking of learning materials in the LMS system. Furthermore, the selected learning materials are visualized in a VR-based learning scenario.
- To produce recommendations according to the level of student knowledge, we determined three criteria as a reference in the MCRS system. The three criteria in question are value, time, and overall assessment.

3. Method and metaverse design

3.1 Metaverse-based mathematics pedagogy media

In this study, we divide the proposed system into two main parts, namely recommendation generator and metaverse visualization, as shown in Fig. 1. In the early stages of using MMPM, players are faced with a pre-test visualization form that contains several questions to measure their level of knowledge based on the criteria for rating value (*R1*), processing time (*R2*), and overall rating (*R0*). Furthermore, the recommendation generator is part of the proposed system that functions to generate recommendation rankings as a reference in learning material selection based on the criteria *R1*, *R2*, and *R3*. We use MCRS to calculate the three rating criteria in the recommendation generator section. Meanwhile, the two sub-sections that support the recommendation generation process in this research are similarity calculation and ranking similarity calculation.

Similarity calculation calculates the similarity between players and all the reference data in the evaluation rating database. While ranking similarity

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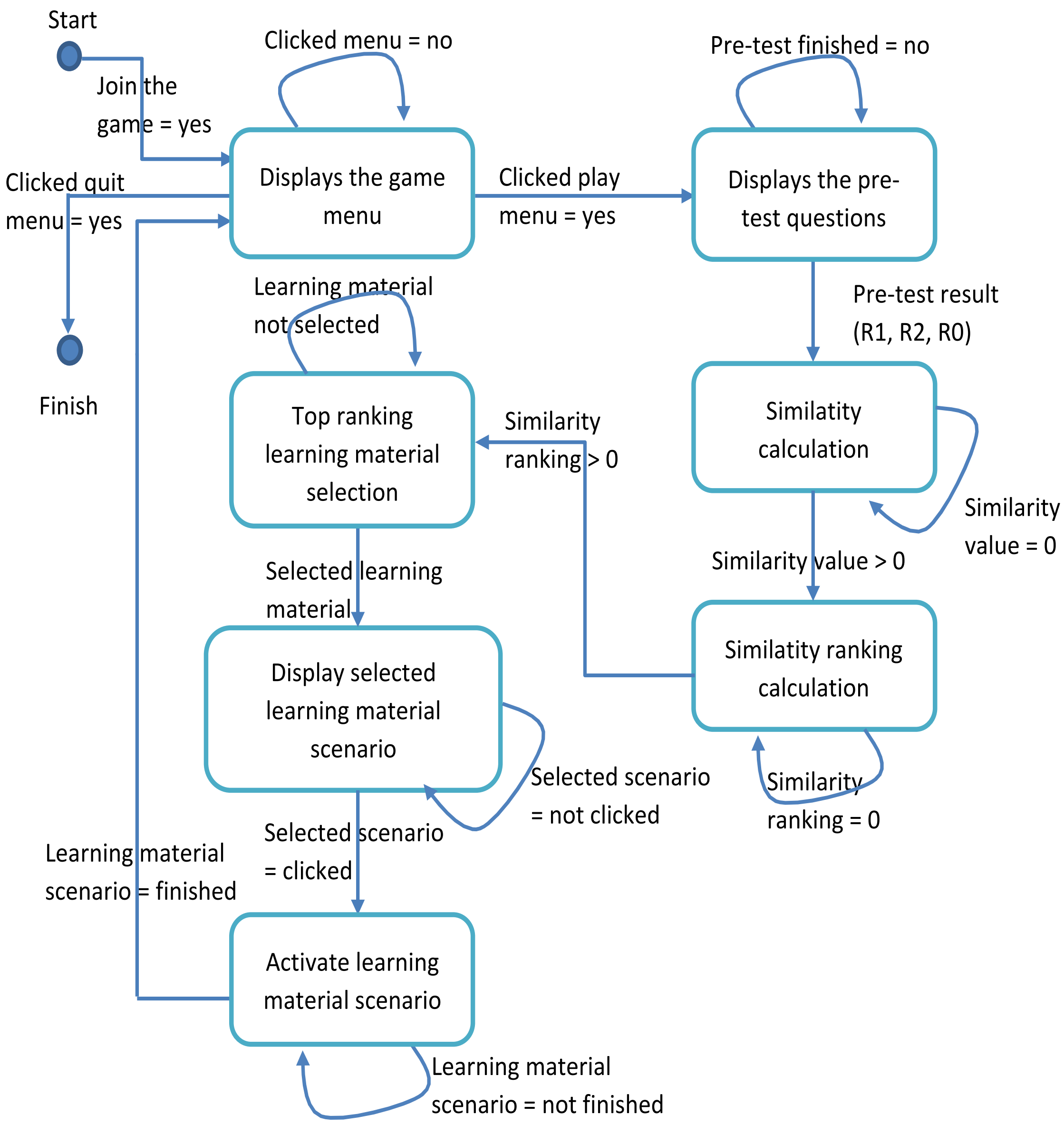


Figure. 2 Scenario design in FSM

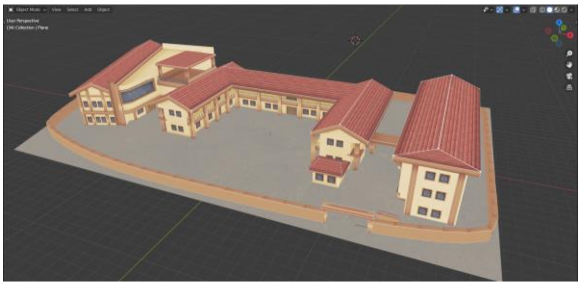
calculation is the process of determining the highest similarity among all existing datasets. Furthermore, in the metaverse visualization section, the highest similarity results are used as a reference to assess the learning material scenario visualized in the selected scenario. The scenario visualization model for the selected learning material in this study is in the form of 3D virtual reality. Furthermore, by utilizing the blockchain network support, each player has the opportunity to interact with other players in the virtual environment metaverse that is built.

3.2 Learning material selection using MCRS

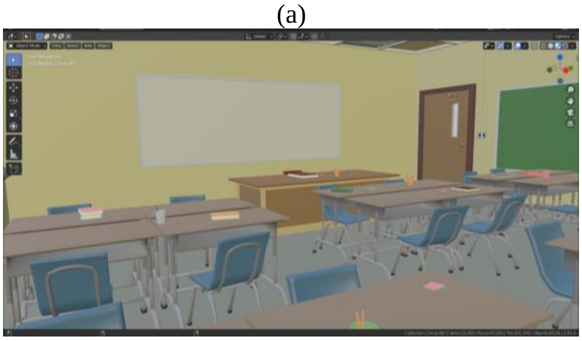
In the learning material selection process, we have determined several rating criteria (R1, R2, and R0) that are needed in computing MCRS. Eq. (1) shows the fundamental equation of MCRS, where R is the rating value of user u to item i. The multi-criteria concept is expected to increase the recommendation generator's ability to produce the most recommended learning material items through the similarity process and ranking similarity calculation. Several popular techniques are used in the MCRS method to calculate user similarity, including Pearson correlation and cosine-based similarity [14].

$$R : u \times i \rightarrow R_0 \times R_1 \times R_2 \quad (1)$$

In this study, we tried to use the cosine-based



(a)



(b)

Figure. 3 Virtual environment design: (a) School environment and (b) Class environment.

similarity technique because it has a more accurate ability to produce recommendations based on multi-criteria [13]. Eq. (2) is the equation for the similarity value $sim(u,u')$ between the new user u and the reference user data u'. The similarity value is the result of a calculation between $I(u,u')$ which is an item that gets a rating from users u and u' with $R(u,i)$ as the rating of the user u for the item i.

$$sim(u,u') = \frac{\sum_{i \epsilon I(u,u')} R(u,i)R(u',i)}{\sqrt{\sum_{i \epsilon I(u,u')} R(u,i)^2}\sqrt{\sum_{i \epsilon I(u,u')} R(u,i)^2}} \quad (2)$$

Furthermore, there are several techniques in the similarity ranking calculation process, including using average similarity $sim_{avg}(u,u')$, worst-case (smallest) similarity $sim_{min}(u,u')$ and aggregate similarity $sim_{agregate}(u,u')$ [14]. In this study, we tried to compare the calculation results of the three techniques shown in Eqs. (3) to (5). In the equation, $sim_c(u,u')$ represents the similarity value to criterion c for users u and u'. On the other hand, k is a variable that represents the number of rating criteria used. At the same time, w_c is a representation of the weight of the criteria that each item has.

$$sim_{avg}(u,u') = \frac{1}{k+1}\sum_{c=0}^{k} sim_c(u,u') \quad (3)$$

$$sim_{min}(u,u') = \min_{c=0,\dots,n} sim_c(u,u') \quad (4)$$

$$sim_{agregate}(u,u') = \sum_{c=0}^{n} w_c sim_c(u,u') \quad (5)$$

3.3 Scenario and environment design

Metaverse development contains elements of gamification, while an integral part of game development is scenario design [25]. In this study, the scenario was designed to visualize the process of transferring knowledge about mathematics subject matter. Fig. 2 shows a scenario design in a finite state machine (FSM) that contains the possibility of player activities when playing MMPM.

The next step after scenario design is the virtual environment design for MMPM. The environment is an asset that serves as a virtual setting in the game. The assets used in this research are 3D assets using 3D blender software. Fig. 3 shows an example of this study's MMPM virtual environment design.

4. Result and discussion

4.1 Data preparation

At the experimental stage, this study uses one of the themes of mathematics learning for high school students, namely building space. There are four items

Table 1. Example of dataset

Datase (U)	Pre-test scores											
	Beam *(i1)*			Cube *(i2)*			Prism *(i3)*			Pyramid *(i4)*		
	R1	***R2***	***R0***	***R1***	***R2***	***R0***	***R1***	***R2***	***R0***	***R1***	***R2***	***R0***
1	6	10	8	6	10	8	6	10	8	5	5	5
2	7	10	8,5	7	10	8,5	7	10	8,5	4	5	4,5
3	3	5	4	8	10	9	8	10	9	8	10	9
4	2	5	3,5	9	10	9,5	9	10	9,5	9	10	9,5
5	1	5	3	10	10	10	10	10	10	10	10	10
6	6	9	7,5	6	9	7,5	6	9	7,5	5	4	4,5
7	7	9	8	7	9	8	7	9	8	4	4	4
8	8	9	8,5	8	9	8,5	8	9	8,5	3	4	3,5
9	9	9	9	9	9	9	9	9	9	2	4	3
10	10	9	9,5	10	9	9,5	10	9	9,5	1	4	2,5

Table 2. Cosine-based similarity and similarity rank calculation (average, worst-case, aggregate) result

(u, u')	Cosine-Based $sim(u, u')$			*R1+ R2+ R0*	Average $sim_{avg}(u, u')$	Worst-case $sim_{min}(u, u')$	Aggregate $sim_{aggregate}(u, u')$
	R1	*R2*	*R0*				
Un1,U1	0,992481	0,913386	0,955477	2,861344	0,715336	0,913386	14,3067202
Un1,U2	0,971217	0,913386	0,942623	2,827226	0,706806	0,913386	14,13612889
Un1,U3	0,941883	0,913386	0,928819	2,784088	0,696022	0,913386	13,92043813
Un1,U4	0,910353	0,913386	0,914505	2,738244	0,684561	0,910353	13,69121946
Un1,U5	0,879637	0,913386	0,900014	2,693037	0,673259	0,879637	13,4651842
Un1,U6	0,992481	0,903475	0,952381	2,848337	0,712084	0,903475	14,24168529
Un1,U7	0,971217	0,903475	0,938103	2,812795	0,703199	0,903475	14,06397445
Un1,U8	0,941883	0,903475	0,922896	2,768253	0,692063	0,903475	13,84126668
Un1,U9	0,910353	0,903475	0,907265	2,721092	0,680273	0,903475	13,60546117
Un1,U10	0,879637	0,903475	0,891578	2,67469	0,668673	0,879637	13,37345102

Table 3. Result of accuracy, precision, recall, and F1 score

Experiment (Item)	*ac* (%)	*pr* (%)	*re* (%)	*F1* (%)
2	92	85	85	85
3	92	85	85	85
4	90	80	80	80

of choice of material to choose from, including material about blocks (*i1*), cubes (*i2*), prisms (*i3*), and pyramids (*i4*). Next, we use the rating criteria dataset from the students' pre-test results to support the experiment in the recommendation generator section. Table 1 shows an example of a small part of the dataset used in this study. The table also indicates that each item has a rating of *R1*, *R2*, *R0* that varies. From a total of 100 data obtained, we divide their use into 80 data for reference data and 20 for testing.

We collect 100 data for each subsection value of the building space for high school students in Malang City through the process of answering on questions and assessments in class. Students are given questions by the mathematics teacher about learning materials for geometric shapes consisting of blocks, cubes, prisms, and pyramids. Then students work on each question given, and the teacher assesses the results of student work and records the duration of the process. We use the value criteria data, the processing time for each subject matter, and the average of the two criteria as the data set for this research. Demographics of the 100 student sample used to support the data set in this study included 54% boy and 46% girl with students aged between 14-15 years.

4.2 MCRS result

This section describes the results of testing scenario generators using MCRS. We show examples of similarity calculation results and similarity rankings in Table 2. The results in the table are the calculations based on user Un1 values with *R1*, *R2*, *and R0* for *i1* (6, 9, 7.5), *and i2* (5, 4, 4.5), *i3* (6, 9, 7.5), and *i4* (6, 9, 7.5). The value of cosine-based similarity and each value of the calculation of ranking similarity have mixed results, according to the rating value of the new Un1 user and the rating value of the dataset used. Fig. 4. illustrates the graph of the calculation results on the value of similarity and similarity ranking using 80 datasets.

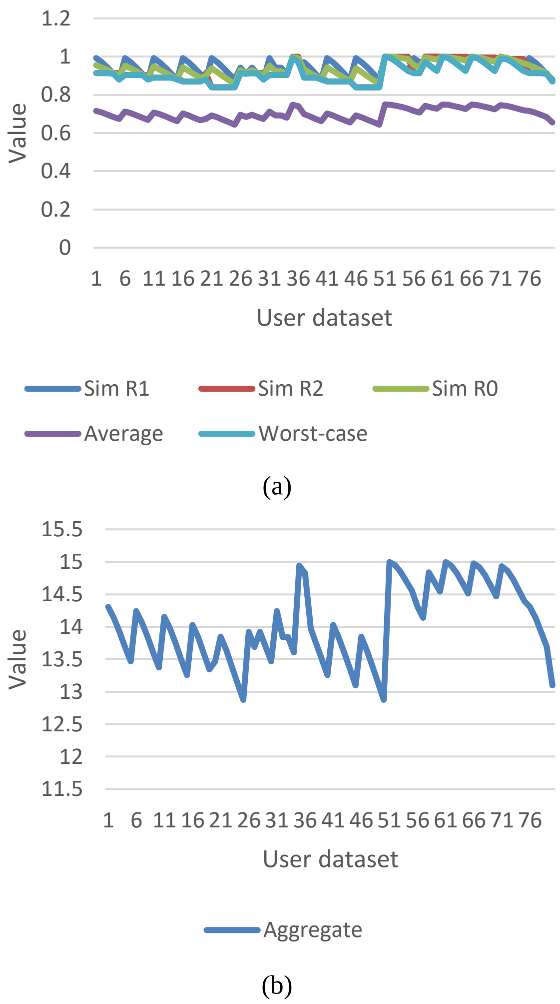


Figure. 4 Similarity calculation result: (a) Similarity, average and worst-case and (b) Aggregate

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In the next phase, we tested the results of the recommendations using the confusion matrix technique. We conducted the test using 20 data with rating ratings for 2, 3, and 4 learning material items. The purpose of testing the confusion matrix is to get the value of accuracy, precision, recall, and F1 score. Some of the variables used to generate these values include True Positive (*TP*), True Negative (*TN*), False Positive (*FP*), and False Negative (*FN*). *TP* is the number of sample system recommendations that follow user recommendations. At the same time, *TN* is the number of samples not recommended by the system or by users. Next, *FP* represents the number of samples recommended by the system but is outside the recommendation of the test user. While *FN* represents the number of samples recommended by the user but not recommended by the system.

$$ac = \frac{TP+TN}{TP+TN+FP+FN} \tag{6}$$

$$pr = \frac{TP}{TP+FP} \tag{7}$$

$$re = \frac{TP}{TP+FN} \tag{8}$$

$$F1 = 2 \times \frac{P \times R}{P+R} \tag{9}$$

Eqs. (6) to (9) is the equation for the values of ac, pr, re, and $F1$. While Table 3 shows the test results on the importance of accuracy (ac), precision (pr), recall (re), and F1 score ($F1$). In this study, we conducted three types of experiments based on the number of item rating criteria data entered by new users. We used 20 test data for each experiment as students who conducted experiments using the MMPM media. Experiments with 2 and 3 input items resulted in better accuracy than when using four input items. Experiments that have been carried out show that the three similarity rank equations (average, worst-case, aggregate) produce the same accuracy value. The highest accuracy value is 92%, while the lowest is 90%. On the other hand, the highest precision, recall, and F1 scores were 85%, while the lowest was 80%.

4.3 Metaverse visualization

We experimented with MMPM development using the Unity Game Engine in this study. By using the game engine, we get the results of building user interfaces, menus, assets, characters, and virtual environments to visualization of learning scenarios. Fig. 5. shows the virtual environment display when

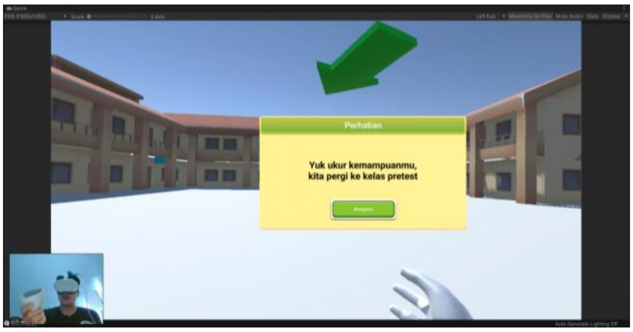

Figure. 5 First entry in MMPM virtual environment

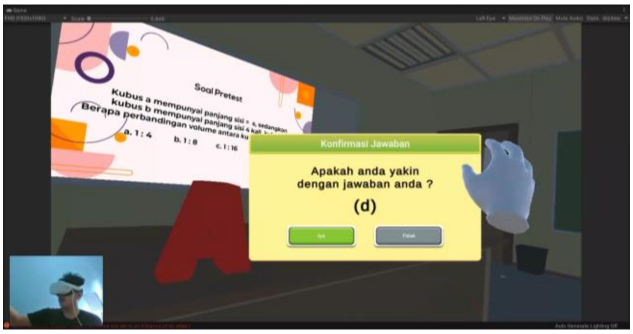

Figure. 6 Pre-test visualization

Figure. 7 Visualization example of learning material scenario

the game is started. While Fig. 6. Presents the display when students do the pre-test. When the pre-test, students are faced with several questions that must be done as a process to measure their knowledge of each learning material. Next, Fig. 7 shows an example of visualizing the recommendation results in the form of a learning scenario about beam. After the system selects the subject matter that is visualized through scenarios and a virtual environment, students can follow the lesson until the end of the scenario.

4.4 Comparison pedagogy media

This section compares the proposed MMPM system with several related research references on mathematics learning media. Table 4 shows these differences in terms of the type of media, the method or concept proposed the adaptive and interactive

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Table 4. Comparison study of mathematics pedagogy media

Reference	Media	Method/Concept	Adaptive	Interactive	Multiplayer
[1]	Game	Educational mathematics game	No	Yes	No
[6]	Interactive multimedia	Geometer' Sketchpad	No	Yes	No
[7]	Interactive multimedia	Interactive mathematics learning	No	Yes	No
[9]	Game	Game-based learning	No	Yes	No
[15]	Interactive board	Smartboard	No	Yes	No
Ours	Metaverse	MCRS-based LMS	Yes	Yes	Yes

capabilities of the proposed system, and the number of players who can use the media at one time. Two other research references use game-based learning media, papers [1] and [9]. However, the two references are still equipped with interactive capabilities, in contrast to the proposed system in this study which has adaptive, interactive, and multiplayer capabilities. In general, interactive abilities are owned by all proposed learning media. Still, only this research can adapt to the knowledge possessed by players and can be played by more than one player.

5. Conclusions

This study proposes metaverse-based mathematics learning media (MMPM) equipped with VR visualization and an LMS system. The task of the LMS system is to provide the MMPM ability to choose mathematics learning scenarios that follow the level of students' knowledge as players of the proposed metaverse system. We use MCRS as a method to support LMS performance in selecting scenarios based on similarity and ranking similarity calculations from new student data compared to previous student datasets. In this study, the MCRS system uses a cosine-based algorithm for similarity calculations, while for ranking similarity calculations we try to use the average, worst-case, and aggregate similarity algorithms.

We built a metaverse-based learning media visualization in the experimental stage using the unity game engine. Furthermore, at the testing stage, this study uses 80 datasets of student grade ratings and 20 new student test data. The test results show that the LMS system in this study succeeded in having the ability to choose mathematics subject matter adaptively according to students' level of knowledge as MMPM players. The MCRS-based LMS system produces the highest accuracy value of 92% for tests 2 and 3 input items, while the lowest is 90% for test 4 input items. The proposed MMPM system equipped with LMS in this study has advantages in the form of adaptive and multiplayer capabilities compared to several related studies in mathematics learning media.

Some parts of this research still need further development and experimentation in an effort to improve the results of the interactive and adaptive metaverse-based learning media concept for players. The first part is related to the methods used to support LMS. We consider that it is necessary to develop an LMS using a decision support system and other recommender systems, to find out which method has the best performance in supporting the LMS system. Another part that requires further research is a blockchain-based data sharing system to support data circulation between players in metaverse-based learning media. In addition, the metaverse-based learning media proposed in this study also needs to be developed in different learning content, for example related to physics, biology, computers and so on.

Conflicts of Interest

The authors declare no conflict of interest**.**

Author Contributions

Conceptualization, Y.M. Arif; methodology, Y.M. Arif, and H. Nurhayati; software, Y.M. Arif, and H. Nurhayati; validation, Y.M. Arif, and H. Nurhayati; formal analysis, Y.M. Arif, and H. Nurhayati; investigation, Y.M. Arif, and H. Nurhayati; resources, Y.M. Arif, and H. Nurhayati; data curation, Y.M. Arif, and H. Nurhayati; writing—original draft preparation, Y.M. Arif; writing—review and editing, H. Nurhayati; visualization, Y.M. Arif, and H. Nurhayati; supervision, Y.M. Arif; project administration, H. Nurhayati; funding acquisition, H. Nurhayati.

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