Math-VR: Mathematics Serious Game for Madrasah Students using Combination of Virtual Reality and Ambient Intelligence

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***Abstract*—The challenge to increasing understanding of mathematics lessons for students in madrasah schools makes the learning process require the support of adaptive alternative learning media. In this study, we propose a serious game-based learning media supported by virtual reality and ambient intelligence technology to equip students with adaptive responses to subject matter scenarios. Ambient intelligence works based on recommendations generated by the Multi-Criteria Recommender System (MCRS). In calculating a similarity between users and reference data, MCRS uses cosine-based similarity calculations, and average similarity is used for ranking. We developed this learning media experiment called Math-VR using the Unity game engine. The experimental test results show that MCRS-based ambient intelligence technology can provide an adaptive response to the choice of geometry subject matter recommendations for students according to their pre-test results. The analysis results show that the recommendation system as part of ambient intelligence has the highest accuracy rate of 0.92 when using 80 reference data.**

Keywords*—*Mathematics; serious game; virtual reality; ambient intelligence; MCRS

I. INTRODUCTION

In Indonesian national education, madrasah is one of the education providers with Islamic overtones. Madrasah play an essential role in educating the nation's children through educational institutions with a combination of general subject matter and Islamic education [1]. Based on its level, madrasah consist of Madrasah Ibtidaiyah, which is equivalent to Elementary Schools; Madrasah Tsanawiyah, which is equivalent to Junior High Schools; and Madrasah Aliyah, which is equivalent to Senior High Schools. Of all these levels, the madrasah has its challenges and obstacles in the learning process for students, especially in mathematics. One indicator of problems in the learning process in madrasah is low student achievement. The leading indicator can be seen from the average National Examination scores for mathematics in madrasah students, which are lower than students from public schools [2] [3]. This problem could be born because more facilities, media, and learning methods still need to be used where it indirectly affects students' understanding of each learning material.

The madrasah curriculum combines general science and Islamic religious knowledge [4] [5]. The breadth of knowledge you want to transfer to students is a different obstacle for students to understand every material the teacher presents. In addition, the level of intelligence and different backgrounds of students makes the level of understanding of students vary. Therefore, to increase madrasah students' understanding of mathematics subject matter, it is necessary to develop learning media that can provide knowledge through interactive visualization and simulation to students. The aim is to make it easier for students to understand compared to when using other conventional learning media such as books or student worksheets. Besides that, it is also necessary to develop learning media that can choose subject matter according to student's level of understanding. Learning media adaptively can provide material according to student's needs as a solution to variations in students' understanding that are different even in the same class.

To answer some of the problems regarding the need for instructional media for madrasah students, in this study, we propose using ambient intelligence-based serious games as an alternative to new interactive, adaptive, fun, and easy-to-understand learning media. Games with interesting interactive and visualization capabilities are needed in learning activities [6]. Serious games are currently being developed as alternative learning media that can provide knowledge to players through the educational, visualization, simulation, exploration, and training functions contained therein [7][8]. Using serious games in education allows players to understand knowledge content in more detail with interactive visualization images via mobile (smartphone) [9]. Furthermore, the addition of ambient intelligence technology in serious games is expected to increase the ability of the system to predict and provide recommendations for learning material choices effectively. That still needs to be better understood by students as game players based on their obtained scores, where scores are an essential part of computer games [10]. Subject matter wrapped in fun interactive games is expected to increase students' interest in and understanding of the subject matter [11].

Ambient intelligence is a technology that makes the virtual environment in the system sensitive, flexible, and adaptive to the presence of users [12]. In this study, we used a Virtual Reality (VR) framework to handle interactive visualizations for students. VR is a type of learning media that is gaining popularity in various fields of science, such as biology [13], tourism [14], digital engineering [15], english [16], and engineering controller [17]. VR-based learning media provides an exciting visualization through the virtual environment provided for players. Furthermore, we also introduce the use of recommender system-based ambient intelligence to predict the level of student understanding so that the system can adaptively choose visualization of mathematics subject matter suitable for madrasah students. The combination of VR technology and ambient intelligence is our effort to increase learning enjoyment, understanding of mathematical content, and students' engagement with the proposed serious game, which we call Math-VR.

II. RELATED WORK

The implementation of serious games as learning media is an exciting field of research and presents a challenge. One of them is that conducted by Hamari et al., who shows that involvement in serious games has an apparent positive effect on the game's challenge and has a positive effect on learning both directly and through increased involvement. Becoming skilled at games does not directly affect learning but increases engagement in games. In the design of educational games, researchers suggest that game challenges must be able to keep up with the development of student's abilities and learning to support continuous learning in a game-based learning environment [18]. In another study, Mohammad Iqbal stated that there were seven steps in designing serious games as learning media. This method begins with analyzing the specification of the pedagogical goals to be achieved and then selecting the type of game model to be used. The third is the adjustment of pedagogical scenarios with fun game scenarios, and the next is the search for software components that can be used. The next step is the detailed description of scenarios and pedagogical quality control, and the final is determining subcontractors' specifications and game design tools [19]. Some of these studies are the primary references of this research proposal. To design serious games as interactive and adaptive learning media, we use the implementation of ambient intelligence supported by Virtual reality technology and a recommender system.

Furthermore, several studies have introduced games as learning media, especially in mathematics for example, M. Hartono et al. Authors use games developed in 2-dimensional visualization so that they are for students studying in elementary school. The experimental results show that students prefer learning mathematics through game media rather than conventional media. In addition, another advantage is that mathematics subject matter becomes more accessible for students to understand [20]. In another study, Sun et al. propose the use of game-based learning media also for mathematics lessons. In the experiment, the authors involving many students and teachers in collecting data through observation and interviews. This study's results indicate that using games as a medium for learning mathematics positively influences learning activities and understanding of mathematics [21]. Based on research by Sun et al. it is necessary to increase adaptive intelligence to the surrounding environment, according to Yunifa et al, one of the adaptive intelligence technologies is ambient intelligence which can be applied to serious games to arrange response scenarios for selecting tourist destinations [22]. In this study using ambient intelligence to set scenarios for selecting responses to games for selecting mathematics learning materials. Some studies that have been carried out use simple game media that still have prospects for improving their abilities, for example, by utilizing game genres with better visualization and simulation capabilities. One of the game genres that can answer the ability challenges from several previous studies is the serious game. Therefore, this study proposes the implementation of serious games as a mathematics learning technology for students in madrasah schools.

Several studies have discussed the idea and design of game-based learning media for madrasah students. One of them is done by Melati et al. in 2022. In their research, authors use educational games as a medium for learning English for madrasah students. They take advantage of educational games that can be accessed online by students. The results of the study show that online game media can help the process of learning English for madrasah students [23]. In contrast to previous research, in this study, we propose using games as a medium for mathematics for madrasah students.

III. SYSTEM DESIGN

This study discusses the proposed serious game system as an interactive and adaptive mathematics learning media for madrasah students. Games are built with story scenarios that describe what is adapted to the subject matter that becomes game content. Therefore, for students who play to get an apparent experience of simulation and visualization of subject matter, we build and design virtual environments and objects that support the process of learning mathematics. Next, we use Unity 3D as the game engine that will be used to build scenarios, objects, characters, and 3-dimensional virtual environments in this serious game.

Fig. 1 shows the proposed mathematics learning system using a serious game. Where to produce interactive and adaptive mathematics learning media, we offer the implementation of ambient intelligence technology in serious games supported by virtual reality visualization and recommender systems. The virtual reality (VR) platform provides visualization and simulation of subject matter content so that it is easy for students to understand, which can be assisted with several types of markers for their interactions. Furthermore, we use the Multi-Criteria Recommender System (MCRS) to provide recommendations for selecting suitable material levels for students based on the scores they obtained through the pre-test.

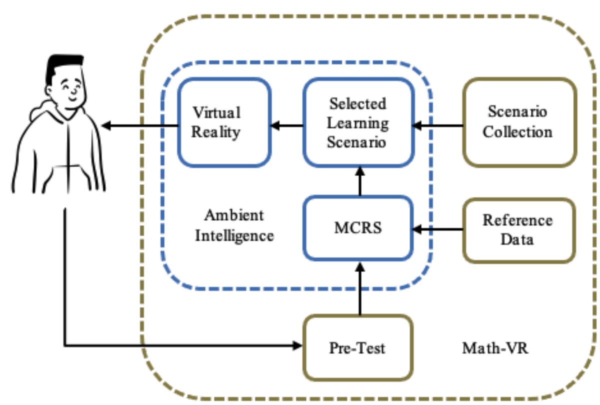

Fig. 1. Architecture of the proposed Math-VR system as mathematics learning media.

In this study, we chose one of the subject matters of mathematics as serious game content, which is about geometric shapes. A VR-based spatial learning game is a game that simulates the activities of students at school. The system starts the game scenario activity by displaying the main menu page, which consists of three options: starting the game, about the game, and exiting the game. After the player selects the start game option, the player will enter the school scene where several classes have different content, and there are material content and tests. When a player completes a test session and gets a score, the system will calculate the Score, so players can get recommendations for subjects that players still must study. Besides recommendations, players can also choose their desired class goals by pressing the destination button. The system will help with the direction of the goal with arrow direction indicators. Fig. 2 shows the rule of a serious game for mathematics educational media based on VR introduced in this study.

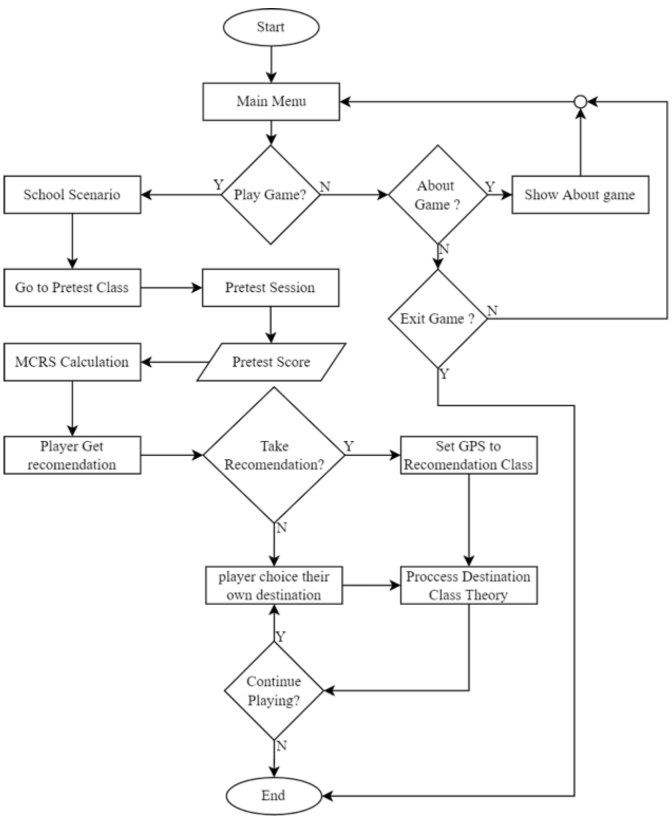

Fig. 2. The rule of proposed Math-VR.

A. Object, Character, and Environment Design

Developing game elements begins with creating assets consisting of the environment, user interface (UI), and characters. We design each asset using Blender software. The characters designed in this game function as non-playable characters (NPC), representing a teacher teaching in class. The process of making a character has a higher level of difficulty compared to making an environment. Character creation requires rigging and animation processes so that the character can move according to the running scenario. The following process is creating 2-dimensional assets in the form of illustrations and UI. Making these assets aims to help users interact with the game. One example is the creation of button images that function as game navigation. As shown in Fig. 3, 4, and 5, we designed the environment and character using Blender software.

Fig. 3. Designing a school environment.

Fig. 4. Designing a class environment.

Fig. 5. Designing game character.

B. MCRS-Based Ambient Intelligence

This study utilized a multi-criteria-based recommender system to provide ambient intelligence capabilities in serious games. MCRS generates recommendations based on player pretest value data at an early stage when playing a spatial learning game. The value data includes the value of the answer score (R1) and the length of processing time (R2). The MCRS system performs calculations using a heuristic approach based on the multi-criteria recommender system (MCRS). Eq. (1) shows the calculation to get the value of R1 after the player completes the pretest session. Twenty questions will be randomized from the 64 questions available in the game database. In the pretest session, besides being required to answer correctly, players must also answer questions as quickly as possible. The faster the player answers the questions, the bigger the Score they get.

$$R1 = \frac{(JS - SS) \times MS}{SF} \quad (1)$$

The calculation that occurs to get the value of R1 is shown through (1). First, the number of questions (JS) is reduced by the number of wrong questions (SS), then the multiplier is multiplied by the correct answers (MS). The purpose of multiplying by the multiplier is to get a score of 100/100 where this value will be displayed on the game interface. In this research, the multiplier value used is 5. Furthermore, the value is divided by the simplified value (SF) or simplified value. The reason is that R1 only has a value range of 0-10. The simplified value in this study is 10. After that, the value of R1 or the first criterion will be obtained.

$$R2 = \frac{\sum_{CT=n}^{JS} CT_n - TS}{JS} \quad (2)$$

In (2), the calculation of the long processing time criterion (R2) begins with the process of obtaining the current time (CT) and start time (TS) values. The following process calculates the time required by the value (CT) minus the value (TS). The process will repeat until all questions (JS) has been answered. In this study, there were five items in each type of question. For example, the cube problem has five questions, five blocks, five prisms, and five pyramids for 20 questions. After all the questions have been answered, all the reduction values will be added and divided by the number of available questions (JS).

R1 and R2 values are rating values used in MCRS calculations. In this study, we used the MCRS algorithm based on a heuristic approach with several steps to calculate the similarity of *u'* and *u* ratings. The first step is to calculate the similarity rating of the new player *u',* and all the ratings of previous players u using the cosine-based similarity formula. At (3), *I(u,u')* is an item rated by players u and u'. While *R(u,i)* is the rating value, new players give to items [24] [25].

$$sim(\mu, \mu') = \frac{\sum_{i \in I(\mu,\mu')} R(u,i) R(\mu',i)}{\sqrt{\sum_{i \in I(\mu,\mu')} R(u,i)^2} \sqrt{\sum_{i \in I(\mu,\mu')} R(u,i)^2}} \quad (3)$$

After the results of the calculation of similarity between players are known, the second step is to calculate the individual similarity values using the average similarity formula $sim_{avg}(\mu, \mu')$ as in (4). This calculation aims to find out the player who has the highest overall Score with the highest level of similarity among all players. The value *n* indicates the number of criteria rated by the player, while $sim_c(\mu, \mu')$ is the similarity for each criterion between user *u* and the previous user u' [26] [27].

$$sim_{avg}(\mu, \mu') = \frac{1}{n+1} \sum_{c=0}^{n} sim_c(\mu, \mu') \quad (4)$$

IV. Result and Discussion

A. The User Interface and Environment Result of Math-VR

In this research, we developed game elements for Math-VR using the Unity 3D game engine. When players start the game for the first time, they will find three options on the main menu, namely "Mulai" to enter the game's gameplay, "Tentang" to find out information about the application, and "Keluar" to navigate out of the application as in Fig. 6. After starting the game, the player will immediately enter the school environment as in Fig. 7. Where at this stage, the system will show the first-person view of players who use VR devices and are synchronized with movements in the virtual game environment. Furthermore, players will be directed using arrows to go to class. Fig. 8 shows an example of visualizing a virtual classroom environment used in learning activities using Math-VR.

Fig. 6. Math-VR menu.

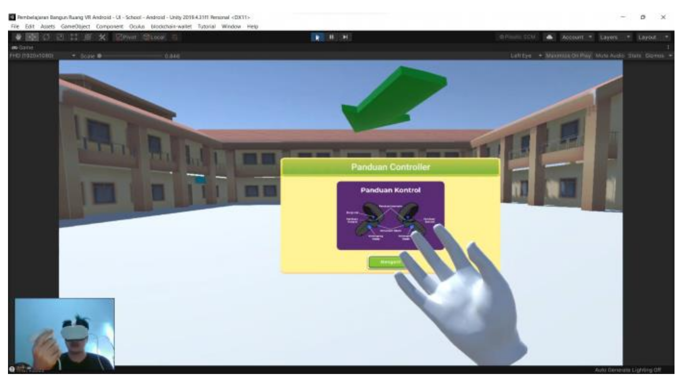

Fig. 7. School environment in the player view.

Fig. 8. Classroom environment in the player view.

When entering the classroom environment, the system provides pre-test questions to the player as the first step to obtaining the rating data needed by the recommendation system. In the pretest class, the Math-VR system guides players to pay attention to the questions on the blackboard and answer them by taking the alphabet according to the selected answer. After the player has answered all the questions, then the game displays the pretest results panel in the form of the Score obtained by the player, the number of questions answered correctly and incorrectly, as shown in Fig. 9. Players can press the "Lanjutkan" button to find out the results of the system evaluation regarding the recommended subjects to study. Fig. 10 shows the display of recommendations generated by the system using the MCRS method to implement ambient intelligence technology in Math-VR. In this session, players can choose one of three subjects that they want to study first. Fig. 11 shows example of the results of the visual display of the condition of the virtual environment when the player has entered one of the learning scenarios about geometric shapes.

B. MCRS-Based Ambient Intelligence Results

In this study, we tried implementing ambient intelligence technology into a serious game proposal using the multi-criteria-based recommender system method. The system uses the results of the recommendations as a reference in responding to players regarding the choice of lesson scenarios that are appropriate to their level of understanding. In the process of generating recommendations, MCRS requires initial data as a reference to predict the similarity of the new user ratings.

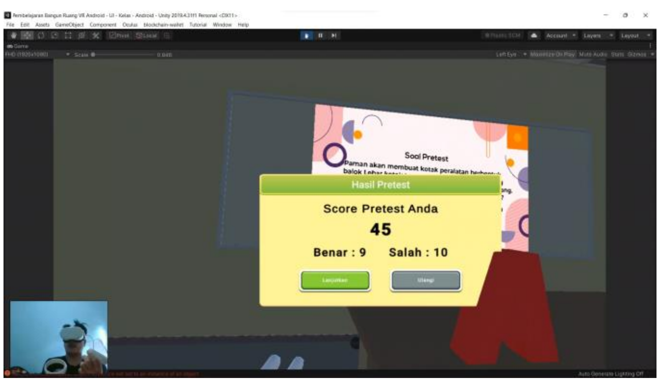

Fig. 9. Pre-test score result.

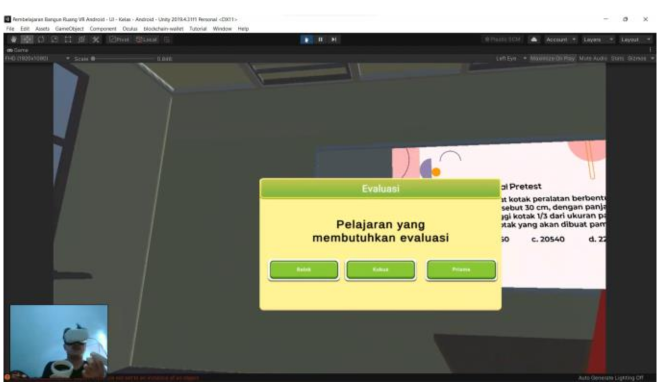

Fig. 10. Visualization of geometry learning material recommendation.

Fig. 11. Example of virtual environment visualization for geometry learning.

In this study, we obtained reference data through a direct test that 125 students attended. There are two assessment factors in the test: the correct or incorrect answer and how long it takes the participant to answer the question. The longer the time it takes, the smaller the Score the participant will get. We also carry out a selection process for each data based on variations in the criteria value. We do not use exact respondent rating data.

Meanwhile, we only use rating data very far from the average participant score. After the data selection process, we got 110 valid test data values divided into two, namely 100 reference data and 10 test data. This study uses five scenarios of experimental testing, namely with 40, 50, 60, 70, and 80 reference data. The aim is to see the relationship between accuracy and the amount of reference data used. At the same time, some of the variables resulting from the testing experiment are precision, recall, accuracy, and F1 Score. Table I shows the test results based on 40, 50, 60, 70, and 80 reference data. We also carry out tests for the results of the Top N recommendations 1, 2, and 3.

TABLE I. RECOMMENDATION SYSTEM TEST RESULTS FOR PRECISION, RECALL, ACCURACY, AND F1 SCORE

Top N	***Result***	***Reference Data***					
		40	***50***	***60***	***70***	***80***	***Average***
1	Precision	0,50	0,60	0,70	0,73	0,82	0,67
	Recall	0,56	0,55	0,64	0,73	0,90	0,67
	Accuracy	0,78	0,78	0,83	0,85	0,92	0,83
	F1 Score	0,53	0,57	0,67	0,73	0,86	0,67
2	Precision	0,61	0,67	0,68	0,75	0,85	0,71
	Recall	0,58	0,60	0,68	0,75	0,85	0,69
	Accuracy	0,63	0,65	0,70	0,75	0,85	0,72
	F1 Score	0,59	0,63	0,68	0,75	0,85	0,70
3	Precision	0,52	0,60	0,64	0,74	0,76	0,65
	Recall	0,60	0,68	0,70	0,77	0,90	0,73
	Accuracy	0,40	0,58	0,60	0,72	0,80	0,62
	F1 Score	0,56	0,64	0,67	0,76	0,83	0,69

Fig. 12, 13, and 14 show the test results in graphical form on the variables precision, recall, accuracy, and F1 Score for 40, 50, 60, 70, and 80 reference data. These results also show that the more test data used, the better the accuracy of the recommendations. The highest accuracy value is 0.92 when using 80 test data for Top 1 recommendation results. While the highest average accuracy value is 0.83 for Top 1 recommendation results, the highest average precision is 0.71 for Top 2 recommendation results, average -the highest average recall is 0.73 for Top 3 recommendation results, and the highest average F1 Score is 0.70 for Top 2 recommendation results.

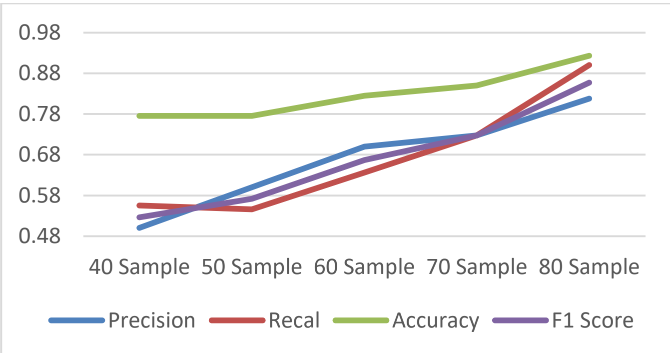

Fig. 12. The test results for Top 1 recommendation.

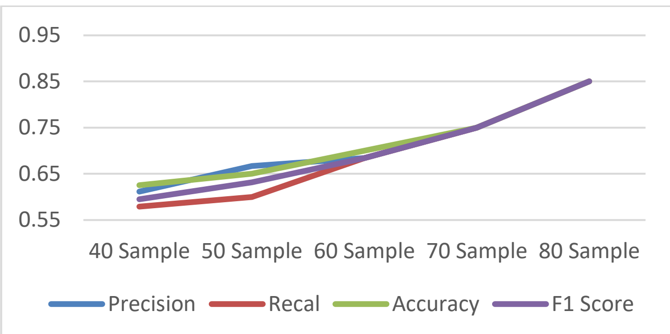

Fig. 13. The test results for Top 2 recommendation.

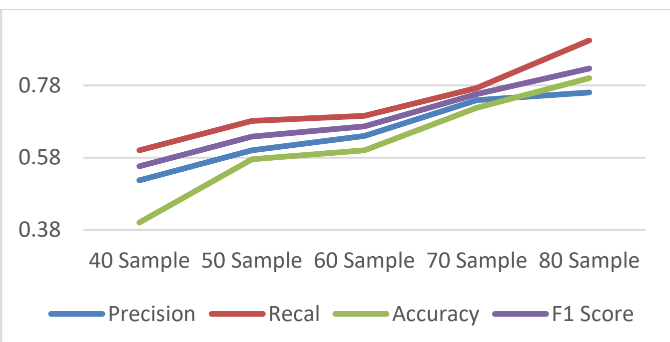

Fig. 14. The test results for Top 3 recommendation.

V. CONCLUSION

In this study, we propose a serious game-based mathematics learning media supported by virtual reality technology and ambient intelligence called Math-VR. This study utilizes a multi-criteria-based recommendation system to generate ambient intelligence system responses. The recommendations generated by MCRS respond to the choice of geometry learning scenarios following the results of the pre-test player. In the MCRS system, the formula algorithm used to calculate similarity is cosine-based similarity, while calculating ranking uses average similarity. In this research, we developed Math-VR using the Unity game engine. Furthermore, the test results show that Math-VR can respond to the recommendation of subject matter scenarios that are adaptive to the results of the pre-test player. The highest accuracy value is 0.92 when using 80 test data for Top 1 recommendation results. While the highest average accuracy value is 0.83, precision is 0.71, recall is 0.73, and F1 Score is 0.70.

Several parts of this research have prospects for further development in future research plans. One of them is the recommendation system-based ambient intelligence section. We can also use machine learning methods to get better results. Besides that, in the following research, Serious games can be used in content other than learning mathematics. To make it more interesting, the VR-based serious game, the subject of this study, can be developed into a metaverse-based learning technology.

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