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Development of Computer Vision-Based Sciences Educational Games for Elementary Schools

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Abstract

The development of computer vision technology has had a significant impact in various fields, including education. Educational games that utilize the concept of computer vision have become one of the innovative methods in interactive learning. This research aims to develop and evaluate the effectiveness of computer vision-based educational games in the context of learning. The research method involves the development of educational games using existing algorithms in computer vision. The games are designed to enhance student's cognitive and psychomotor aspects in understanding basic mathematical concepts. The research also involves the design and implementation of an intuitive and engaging user interface to increase student engagement in learning. The effectiveness of the educational games is evaluated through a case study involving a group of students and teachers. Students are given access to the educational games and are tasked with completing a series of challenges and activities related to basic mathematical calculations. Data collection is done through user satisfaction surveys to assess the impact of using educational games on learning interest. It was found that 80% of the educational games helped student's understanding of learning concepts. The developed games are also suitable for the level and knowledge skills of 2nd and 3rd grade students, with a percentage score of 60%. There were constraints in the development of these educational games, with 30% of the respondents experiencing difficulty in usage. Sometimes hand movements cannot be captured properly if the distance from the camera is too close or too far.

Keywords: Computer Vision, Education Game, MediaPipe

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I. INTRODUCTION

Educational games are a type of video game designed to help players acquire specific knowledge or skills while playing [1]. The main goal of educational games is to make learning more interesting and enjoyable so that players feel more motivated and engaged in the learning process. Initially, educational games were mainly used in formal educational settings, such as schools or universities, to help teachers introduce certain concepts and improve student's skills in fields like mathematics, science, and language [2]. Over time, educational games have spread to various industries and environments, including households, companies, and governments. The benefits of educational games include helping to build cognitive skills such as problem-solving, motor skills, social skills, teamwork, and improving short-term memory [3]. Additionally, educational games also help improve communication skills and motivate players to continue learning [4]. One popular type of educational game used to improve cognitive aspects are puzzle games, such as sudoku, virtual quizzes, and jigsaw puzzles [5]. These games require players to think critically and strategically to find solutions to problems [6]. Additionally, educational games that require psychomotor skills are also very popular. Educational games that use computer vision technology to enhance cognitive and psychomotor skills are increasingly popular because this technology allows games to become more interactive and enables a more enjoyable learning experience [7].

In the world of educational games, computer vision technology is being utilized to detect player movements and interactions with the game. By doing so, the game can respond to the player's actions in real-time, providing a more interactive and engaging learning experience. Puzzle games that use computer

vision technology can also help improve cognitive and psychomotor skills [5]. Therefore, the design of effective educational games must consider the learning objectives and provide a meaningful and beneficial learning experience. According to research about Educational Game for Introducing Indonesian Sign Language System Using MYO Armband in Client Server Architecture is quite effective in recognizing hand movements for the alphabet and simple words in Indonesian Sign Language with an accuracy of 93.08%. This makes it easier for children to recognize sign language in a more interactive manner [8]. Furthermore, research about Educational Game for Introducing Plants to 3rd Grade Elementary School Children Based on Augmented Reality explains that the implementation of AR educational games for plant recognition can enhance the learning interest of 3rd grade students in a more interactive manner. This is because plant recognition is not just a visual display, but the availability of text descriptions with sound can improve the memory of elementary school students in recognizing different types of plants. Computer vision technology can be an effective tool in improving player interaction with the game, but effective and engaging game design is also crucial to achieve the learning objectives [9]. Therefore, educational game developers need to ensure that computer vision technology is integrated with effective and engaging game design.

It is important to choose the right type of game for specific learning purposes. In this regard, the development of educational games needs to consider the types of cognitive and psychomotor skills that are to be enhanced, and to select the appropriate type of game that aligns with those learning objectives. To determine its effectiveness, the implementation of educational games will be tested on elementary school children or teachers [10]. Research about The Effects Of Two Digital Educational Games On Cognitive And Non-Cognitive Math And Reading Outcomes explains that the cognitive results of the study show that children who play educational games demonstrate better performance in estimating number lines and reading competence [11]. Video games provide a means to improve human cognitive abilities. Cognitive skills such as perception, attention control, and decision-making improve when subjects are trained with video games [12]. The research about The Effect of Game-Based Learning on Academic Achievement Motivation of Elementary School Students shows that students who play computer games play an important role in acquiring higher skills than those trained in traditional ways. The research results also show that computer-based educational games with flexible, competitive, and engaging content provide conditions in which students learn through their activities and direct their minds through behaviors in which they actively participate [13].

In recent years, advances in computer vision and AI technology have made it increasingly possible to develop more advanced and effective educational games in improving cognitive and psychomotor skills. However, there are still challenges and issues that need to be addressed, such as digital divide and privacy and security concerns. Therefore, further research is needed to optimize the use of computer vision technology in educational games and ensure that games designed with this technology are truly beneficial and safe to use. Thus, in this study, an educational game was developed that implements computer vision as a learning medium. The tasks for the researchers are divided into two parts: first, how the developed application can model hand landmarks that will be used as a reference for hand movements in the developed game. Second, the researchers conducted a survey to determine if the game created is beneficial for children, especially in the research location.

II. RESEARCH METHOD

Based on Figure 1, it shows the steps taken bye researchers to develop educational games. Broadly divided into two parts, namely Hand Detection and Game Development and Testing.

A. Hand Detection and Hand Landmark

MediaPipe is a powerful tool that facilitates the development of applications involving real-time visual analysis, such as augmented reality (AR), human-machine interaction, and many more. By providing pre-trained solutions, MediaPipe makes it easier for developers to implement this technology. The first basic objection to MediaPipe is its ability to provide real-time visual analysis. This is essential for applications that require instant feedback based on visual data, such as AR filters or gesture recognition. MediaPipe's pre-trained models and processing pipelines allow developers to quickly integrate real-time visual analysis into their applications, saving them time and effort in developing these complex systems from scratch [14].

One aspect that can be utilized from MediaPipe is its ability in hand gesture recognition, which allows to identify and monitor the movement of human hands in images or videos. This feature has the capability to recognize the position and movement of hands, including the recognition of hand gesture patterns. The hand tracking process using MediaPipe is used to detect and track human hands in videos or real-time

camera feeds. MediaPipe is a framework developed by Google for visual media processing, including hand detection and tracking [15].

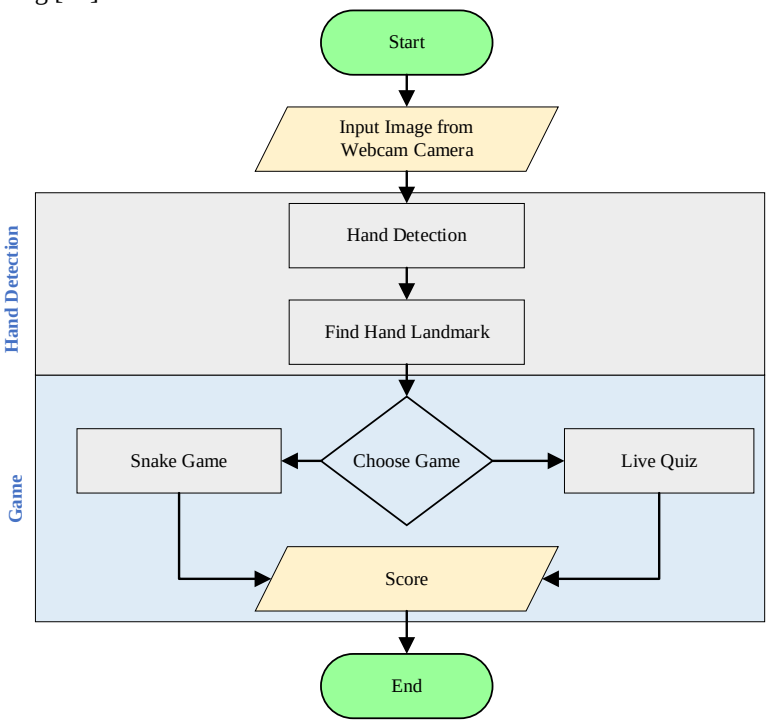

Fig. 1. Flowchart Education Game Based Computer Vision

The first step is to detect the presence of hands in the image or video. MediaPipe uses neural networks to identify regions that may contain human hands. The result of this stage is a bounding box that shows the estimated position of the hand. Once the hand is detected, the next step is to estimate the positions of key landmark points on the hand. These points include fingertips, knuckles, wrists, and so on [16]. MediaPipe uses regression models to predict the position of hand landmarks based on the provided image. To address fast hand movements and pose changes, MediaPipe employs hand tracking techniques. Hand tracking utilizes information from previous frames to refine and predict the position of the hand in the current frame. This tracking technique helps maintain consistency in hand tracking and minimize potential errors. In Figure 2, the real-time usage of MediaPipe Hand Tracking is shown to accurately detect hand landmarks.

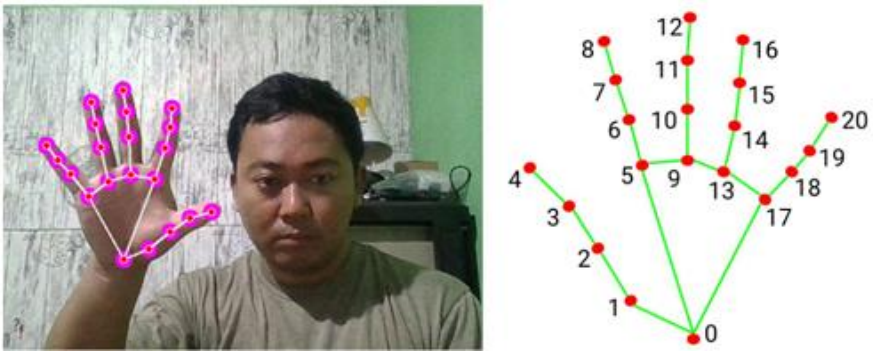

Fig. 2. Hand Detection and Hand Landmark

B. Development and Testing the Game

The developed educational game consists of two types, namely Snake Game and Virtual Quiz. Figure 3 shows the interface of the snake game (a) and virtual quiz (b). In the snake game, the snake can only be moved using the index finger. Based on the results of the previously obtained hand landmarks, only landmark point 8 is used. The snake game is a game that hones psychomotor skills to identify object locations. Every time the snake eats a donut, the score will increase. At that time, a random command is also executed to place the coordinates of the next donut position. This game will stop if the snake's head hits its body. The virtual quiz game is used to hone the cognitive abilities of students, especially in grades

2 and 3 at SDN Wonorejo 01 Talun. This game is run by providing basic multiplication math problems. The questions can be in the form of story problems or direct calculations. The questions and answers are stored in .csv file format. To answer each question in the virtual quiz, students are required to make a hand gesture like scissors. This can be done by taking the minimum distance from the movement of landmarks 8 and 12 as shown in Figure 2.

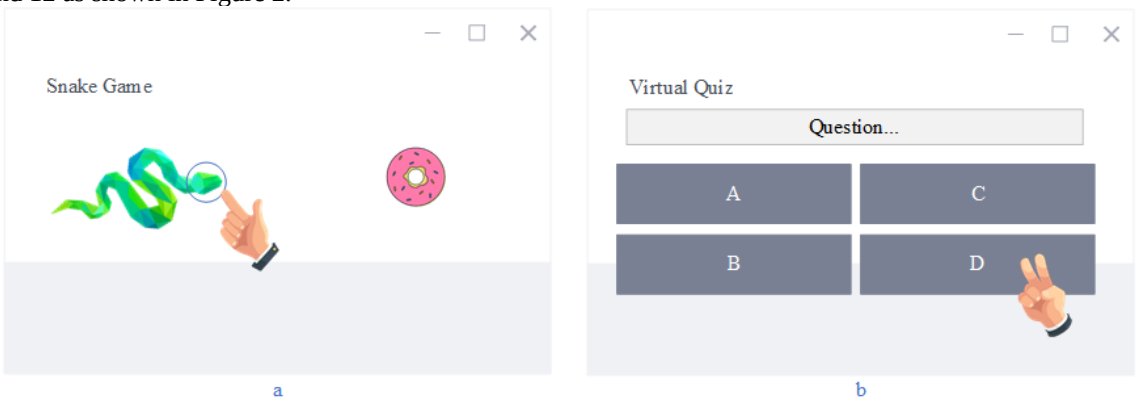

Fig. 3. Game User Interface

III. RESULTS AND DISCUSSION

At this stage, preparation is essential in the development of the educational game. The educational game will be implemented using the Python programming language, with specific hardware requirements that are outlined in Table 1.

TABLE I. HARDWARE REQUIREMENTS

Hardware	Description
Intel I3-3007	Processor
HDD 500GB	Harddisk
Logitech C170	Webcam
Ram 4GB	Memori

Table 2 demonstrates the necessary software required for the development of educational games in this study. Python programming language and PyCharm IDE were utilized in order to facilitate the game development process efficiently.

TABLE II. SOFTWARE REQUIREMENTS

Software	Description
PyCharm	IDE Application
Python 3.8	Library

Meanwhile, the required Python libraries for the development of an educational game are shown in Table 3 below. Several libraries such as OpenCV, MediaPipe, CVZone, and Time are needed for the development of this educational game. OpenCV library is able to recognize objects within the educational game, while MediaPipe is used as a Machine Learning Model that can detect, recognize, and perform hand gestures within the game.

TABLE III. PYTHON LIBRARIES

Library	Description
OpenCV	Open source computer vision
MediaPipe	Library machine learning model
CVZone	Python library for handtracking
Time	Library for timing Virtual Quiz

A. Hand Detection dan Hand Landmark

Each hand landmark is represented by 2D coordinates relative to the image or frame. These coordinates can be used to depict and track the pose of the human hand. Hand detection begins by reading input in the form of video feed from a webcam. The image from the video undergoes preprocessing stages, such as color normalization or scaling, to enhance the quality and speed of the process. MediaPipe uses a pre-trained hand detection model. This model is used to identify and delimit the regions where hands may be

present in each video frame. The result of hand detection is a bounding box that encompasses the hand in the video frame. The hand landmark process is initiated after the hand is detected by the application. MediaPipe focuses on the region inside the bounding box, which is considered as the "Region of Interest" (ROI). MediaPipe uses a pre-trained hand landmark model to locate the positions of the key points (landmarks) on the hand. These landmarks include fingertips, palm, and other parts. After the landmark model is executed on the ROI, the result is the 3D coordinates of the key points on the hand. These coordinates provide information about the relative position of each landmark in 3D space with respect to other points. The results of the hand detection and hand landmark processes are shown in the Figure 4.

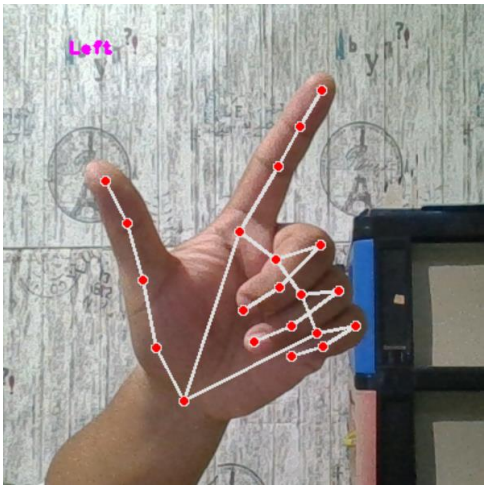

Fig. 4. Hand Detection and Hand Landmark

B. Snake Game Implementation

Snake Game is offered by the author is to do approach using by computer vision technology. The creation of this game uses the Python programming language with the help of the MediaPipe library. The educational game works like the usual snake game, but what sets it apart is the use of computer vision with the help of a webcam. The snake will be moved using the index finger. In addition, there are other modifications related to the snake's food being in the form of donuts to attract student's interest in playing this game. Figure 5 shows a simulation of the Snake Game.

In playing this game, students will be invited to move their index finger to the webcam to play the snake. Snake Game is created to measure student's psychomotor skills by observing their responses to objects detected on the monitor screen. In the main objective Snake Game is to eat the randomly placed donuts on the screen. As the player navigates the snake using their finger to successfully eating a donut, it will cause the snake to grow longer and increase the score. However, if the player accidentally controls the snake to collide with its own body, the game will come to an end as depicted in Figure 6. The game will then display the final score obtained by the player. This game requires a high level of precision, patience, and focus in order to emerge victorious. The goal of the game is simple to eat as many donuts as possible and continue to grow the length of the snake. The challenge of this game is when the snake becomes longer, the maneuvering it around the screen becomes more challenging and difficult to control it. The player must be mindful of the snake's body and plan their moves carefully to avoid collision. Additionally, the random placement of the donuts adds an element of unpredictability to the game. This requires the player to stay attentive and scan the entire screen for potential donut locations. It may be tempting to move quickly to capture the donuts, but patience is key in ensuring that the snake does not inadvertently crash into itself. Furthermore, the game demands a high level of focus from the player. With each donut consumed, the snake grows longer, and the potential for collision increases. The player must remain concentrated on the screen and be mindful of the snake's movements at all times.

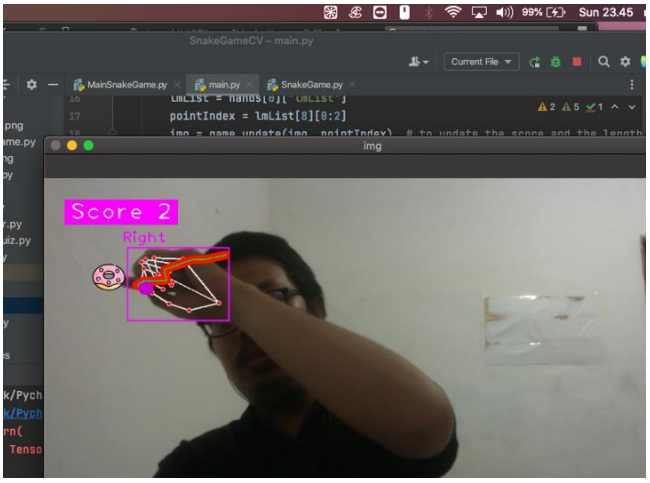

Fig. 5. Gameplay When Successfully Consuming a Donut

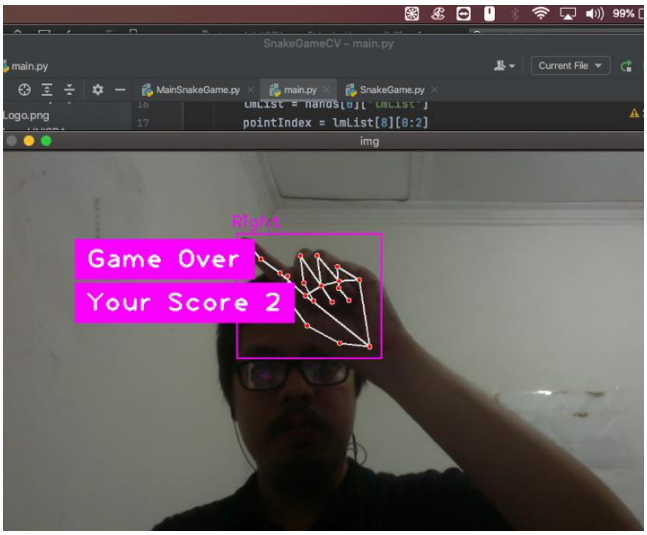

Fig. 6. Game Over

C. *Virtual Quiz Implementation*

The Virtual Quiz is an educational game that can help students to learn basic mathematical knowledge. The purpose of creating this type of game is to improve student's cognitive and psychomotoric skills. To enhance the playing experience for students, the author implemented an answer selection approach in the Virtual Quiz using computer vision technology. Students will be prompted to choose answers by making pinching gestures to select the correct answer. This process is shown in Figure 7.

To play the game, students will see questions that appear on the main layer. The questions and answers will be randomized to challenge the students in playing the game. The questions and answers in this educational game are taken from a .csv file as a data bank. Students will answer questions by selecting the correct answer and confirming it by pinching one of the provided answer options. Once the answer is confirmed, the question will proceed to the next. After all questions are answered, the percentage of correctly answered questions will be displayed. In Figure 8, the display shows when the students have completed all the questions and successfully answered some of the given questions. With the presence of this virtual educational game, it is expected that students can learn in a more interesting, interactive, and enjoyable way.

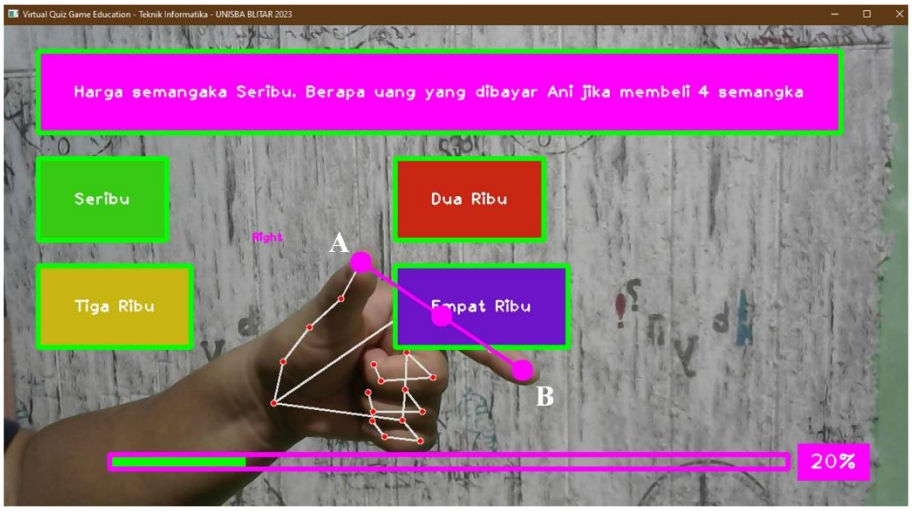

Fig. 7. Virtual Quiz User Interface

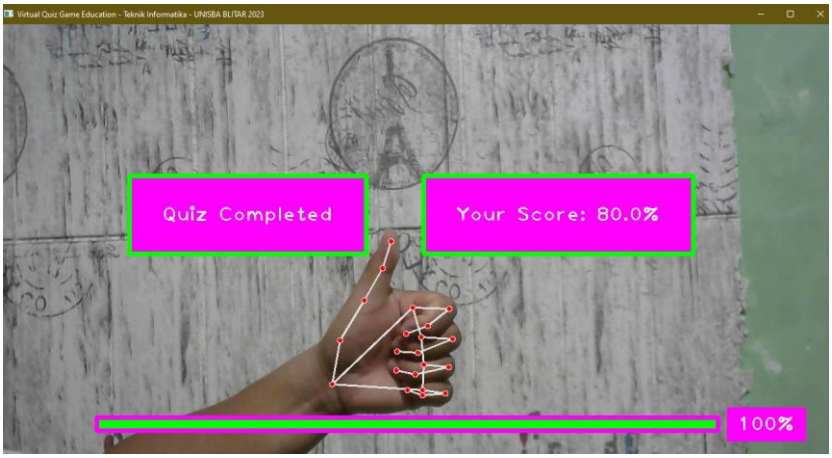

Fig. 8. Result Virtual Quiz

D. Results

The development of educational games has become an increasingly popular method of engaging students in learning. In order to measure the interest of students in learning through an educational game developed by researchers, a survey was conducted. The survey was given to students with the assistance of teachers to input their answers. Additionally, the survey was also conducted with the classroom teachers. Table 4 shows a sample of the contents of the questionnaire to determine the impact of this educational game. Each question on the questionnaire uses the Likert scale. This scale consists of questions followed by a series of answer choices, representing the level of agreement or disagreement of the respondents. The answer choices are in the form of intensity levels, such as "Strongly Agree" to "Strongly Disagree". Each response choice is given a numerical score, for example, from 1 to 5. This score can be added up to produce a total score or can be averaged to represent the overall view of the respondents towards a series of statements.

The questionnaire was distributed by the researchers to 20 respondents, consisting of 18 students and 2 teachers at SDN 01 Wonorejo Talun, specifically in grades 2 and 3. Respondents were asked to indicate their level of agreement or disagreement with the statements. The results of the questionnaire were then analyzed to determine the impact of using computer vision educational games on student's learning interest. Analysis of the Likert scale results can provide insights into the preferences, attitudes, or views of the respondents on a specific topic.

Educational games have the potential to positively impact student's learning interests. By creating a fun and interactive learning environment, students are more likely to engage and develop a genuine interest in the subject matter. The use of the Likert scale in the survey allows for a comprehensive analysis of the respondents' perspectives on the educational game. By understanding the level of agreement or

disagreement with the statements, researchers can assess the effectiveness of the educational game in capturing and maintaining student's interest in learning. This type of assessment is crucial in evaluating the overall impact of the educational game on student's learning experience.

TABLE IV. QUESTIONARY

Number.	Question	SA	A	U	D	SD
1	Do you think educational games can help improve understanding of learning concepts?					
2	Do you feel educational games help improve your cognitive understanding of the subject matter?					
3	Do educational games help you develop psychomotor skills, such as hand-eye coordination?					
4	Are educational games with computer vision really interesting to play?					
5	I feel like this educational game isn't too difficult to use?					
6	The interactive features in the game help me actively participate in the learning process					
7	The graphics and animations in the game make the learning material more interesting					
8	I feel this game suits my knowledge and skill level					
9	Using games as a learning tool makes the learning process more enjoyable					
10	This game combines both entertainment and learning aspects					

Information:
SA (Strongly Agree - 5), A (Agree - 4), U (Undecided - 3), D (Disagree - 2), SD (Strongly Disagree -1)

TABLE V. QUESTIONARY RESULTS

	SA	%	A	%	U	%	D	%	SD	%
Q1	16	80%	4	20%	0	0%	0	0%	0	0%
Q2	6	30%	10	50%	4	20%	0	0%	0	0%
Q3	5	25%	10	50%	5	25%	0	0%	0	0%
Q4	10	50%	8	40%	2	10%	0	0%	0	0%
Q5	8	40%	6	30%	6	30%	0	0%	0	0%
Q6	8	40%	8	40%	4	20%	0	0%	0	0%
Q7	7	35%	8	40%	5	25%	0	0%	0	0%
Q8	4	20%	12	60%	4	20%	0	0%	0	0%
Q9	11	55%	5	25%	4	20%	0	0%	0	0%
Q10	11	55%	8	40%	1	5%	0	0%	0	0%

Information:
Q1-Q10 (List of Question in Questionary)

Based on the results in Table 5, it can be seen that none of the respondents answered disagree or strongly disagree to any of the questions in the questionnaire. This indicates that the application is appealing to both students and teachers. The educational game also shows that 80% find it very helpful in improving student's understanding of learning concepts (Q1). In addition, the developed game is also suitable for the knowledge and skills of 2nd - 3rd grade elementary school students, as indicated by a 60% rating (Q8). However, 30% of respondents experienced difficulties in using the educational game with computer vision. This is expected due to the limitations of the resolution of the webcam used to capture movements. When the distance from the webcam is too far, the application often misinterprets hand movements for controlling the snake game or answering virtual quizzes. However, being too close to the camera is also not feasible, as the application uses the distance between the thumb and index finger to answer virtual quizzes, which can lead to automatic selection of answers even if the student has not finished reading the question.

IV. CONCLUSION

Based on the research results, it can be concluded that this computer vision-based educational game can effectively identify hand movements. Landmarks are created using the MediaPipe library to detect hand movements. The hand landmarks model is used to control the movement of the snake's head in the snake game and to answer questions in the virtual quiz. The snake game is designed to train the psychomotor skills of eye movements and object recognition. The virtual quiz is used to develop and enhance the cognitive abilities of second and third grade elementary school students. To assess the impact of using computer vision-based educational games, the researchers distributed a questionnaire to 20 respondents with 10 questions using a Likert scale. The evaluation results from students and teachers showed that the science educational game, consisting of the Snake Game and Virtual Quiz, had a high level of reliability and validity at 80%. The game successfully increased student interest in the learning concepts. The game also aligned with the student's knowledge and skill levels at 60%. The concept of game-based education also increased student participation in improving focus and precision during gameplay. However, the research also identified some challenges, as 30% of the respondents experienced difficulties in playing or

using the educational game. For future research, it is necessary to develop educational media with different case studies to make it easier for students to engage with the learning material. Additionally, the use of sensors to read hand movements for better stability is required. In conclusion, this study has demonstrated the effectiveness of computer vision-based educational games in enhancing student learning and engagement. Despite some challenges, the overall impact of these games on student interest, skills, and participation is significant. Further enhancements and developments in educational gaming media will continue to improve the learning experience for students.

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