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Quantum teaching based on augmented reality to elevate critical thinking and metacognition of senior high school students in Indonesia

Bea Hana Siswati [a,1*], Firda Ayu Pitaloka [b,2], Bevo Wahono [c,3]

[a,b,c] University of Jember, Jl. Kalimantan no. 37, Jember, 68121, Indonesia
[1] beahana.fkip@unej.ac.id*; [2] 200210103006@mail.unej.ac.id; [3] bevo.fkip@unej.ac.id
* author correspondences

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ABSTRACT

This study investigates the effect of the Augmented Reality (AR)-based Quantum Teaching model on high school students' critical thinking and metacognitive skills in biology. The need for innovative learning models is urgent to enhance students' higher-order thinking abilities, which are crucial for meeting the demands of 21st-century learning. This research employed a quasi-experimental pre-test post-test control group design involving grade XI biology students at Pakusari State High School during the 2023/2024 academic year. Random sampling assigned class XI 5 as the experimental group and XI 4 as the control group. Data collection methods included observations, interviews, essay tests, and documentation. Data analysis using ANCOVA via SPSS version 26 revealed significant improvements in both critical thinking and metacognitive skills in the experimental group compared to the control group. These findings demonstrate that the AR-based Quantum Teaching model effectively enhances students' cognitive and self-regulatory skills in biology learning. The study concludes that integrating AR technology within innovative teaching models can foster critical competencies essential for students' academic success and lifelong learning. The implications of this research suggest that schools and educators should consider adopting AR-supported pedagogies to enrich the learning experience and promote deeper understanding. Educational stakeholders are encouraged to invest in teacher training and digital infrastructure to support the successful implementation of such models. Furthermore, this study provides a foundation for developing curriculum innovations that combine interactive technology and student-centered approaches, aiming to prepare learners with the critical and metacognitive skills necessary for future academic and professional challenges.

INTRODUCTION

Students often experience boredom in learning. One of the causes of boredom can stem from the school environment, such as a curriculum that is perceived as too heavy, ineffective

teaching methods, or teacher treatment that is inappropriate and oppressive, combined with academic demands and school regulations. This learning boredom can cause students to lose motivation and interest in learning, and if left unchecked, it can lead to long-term academic stress (Agustina et al., 2019). Apart from that, the occurrence of *teaching loss* (loss of learning) due to the *COVID-19 pandemic* has made gaps in learning even more pronounced. Therefore, the government is making efforts to restore learning, one of which is by launching an independent curriculum (Idhartono, 2022), known as The Merdeka Curriculum. This curriculum emphasizes soft skills and character development, including critical thinking skills.

According to Julian and Suparman (2019) Critical thinking is the ability to organize and make informed decisions to solve problems and analyze them in scientific contexts. Critical thinking forms the basis for other abilities, one of which is metacognitive skills. Metacognitive skills are very important in learning and everyday life. Metacognitive skills provide advantages for students in solving problems (Aldiono et al., 2022). This skill is also related to the effectiveness of students' own learning methods (Suri et al., 2020). Metacognition involves students in reflecting on their thought processes when solving problems (Setiawan et al., 2020). Even though it is important, many cases show low metacognitive abilities, such as students not being able to self-monitor or not knowing the learning goals (Lestari et al., 2019). Each student has the ability to capture different lessons and has unique insights in exploring science. Knowledge obtained from learning results produces an understanding of the material being taught (Syazali, 2021). However, most teachers today tend to direct conceptual knowledge to factual, which causes students' low understanding of concepts (Ulfa & Rozalina, 2019) .

Biology learning is often called a difficult subject to learn because it has many foreign terms, very dense material, and a lot of memorization (Jayawardana & Gita, 2020). The digestive system material is one of the subjects that can be quite challenging for students. Based on research conducted by Sari et al., (2022), the factors causing these difficulties include too much Latin, reaching 88.01%; difficulty understanding material from the school handbook (81.09%); the teacher's explanation was poorly understood (67.60%); lack of books from other sources (61.42%); lack of learning media (60.11%); and the material seems abstract (53.75%). Therefore, biology subjects are a frightening prospect and can create a sense of boredom for students if an inappropriate learning model is applied (Sari et al., 2022).

Quantum Teaching learning model is a learning model that has a background and strategy for improving the teaching and learning process, and making the process more enjoyable (Nasir & Amri, 2022). The *quantum teaching* learning model is an accelerated learning model *that* makes learning comfortable and enjoyable. The *quantum teaching* model has steps in the learning process known as TANDUR. TANDUR is an abbreviation of grow, experience, name, demonstrate, repeat and celebrate. This learning model involves students actively during learning activities. Apart from that, students will also learn in a pleasant atmosphere so that they will not easily feel bored during learning activities. The advantages of the *quantum teaching* model are: 1) it can guide and direct students' way of thinking; 2) centered on what students experience in their learning process; 3) grow and create students' desire/interest in learning; 4) create a sense of cooperation between students; 5) offer a learning process that is fun and easy for students to understand; 6) create students' self-confidence; 7) create enjoyable learning; 8) motivate students to continue to develop; 9) students are free to express themselves; and 10) foster a sense of idealism, passion

and love for teaching in teachers (Yeniverawatiwote, 2020). With these efforts, it is hoped that students' difficulties with the material can be resolved, and students' abilities will increase.

However, *quantum teaching* is less effective without supporting media. Moreover, currently technology is developing rapidly so that conventional media such as torsos, which require expensive costs to purchase, can be overcome. *Augmented Reality* media is a solution to the limitations of media and costs. The advantage of Augmented *Reality* is that it displays attractive and representative images, making it easier for teachers to focus attention and increasing student motivation during learning activities. Learning media is said to be good if the media can provide feedback and become a tool to support student learning achievement (Oktaviana et al., 2022).

Quantum Teaching research was conducted on class XI students at SMAN 5 Barru which showed that there was an influence of the *Quantum Teaching learning model* on critical thinking skills (Nasir & Amri, 2022). However, there is still no research on the influence of the Quantum Teaching learning model based on Augmented Reality media, digestive system material on the critical thinking skills and metacognitive skills. It is necessary to conduct research regarding the influence of this model on high school biology students.

METHOD

The research was conducted at Pakusari State High School, Jember and its implementation started from August 21 to September 12 2023 in the 2023/2024 academic year which is in an odd semester. The samples are two classes from class XI biology, namely class XI 5 (as the experimental class) and the control class was XI 4. Determining the research sample used an equality test by carrying out a normality test and homogeneity test. After the tested data shows normal and homogeneous data, the next step is to determine the sample. The sampling technique in this research was random sampling with a lottery technique to determine the experimental class and control class. The type of research used is Quasi Experiment in the form of pre-test post-test control group design.

Table 1. Research Design

Group	Pre-test	Treatment	Post-test
E	P_1	X_1	O_1
K	P_2	X_2	O_2

Source: (Anggara & Rakimahwati, 2021)

Information:
E = Experimental class
K = Control class
P_1 = Pre-test results in the experimental class before being given treatment
P_2 = Pre-test results in the control class before being given treatment
X_1 = Treatment of the teaching and learning process using the Quantum Learning model based on Augmented Reality
X_2 = Treatment of the teaching and learning process using conventional models
O_1 = Post-test results in the experimental class after being given treatment
O_2 = Post-test results in the control class after being given treatment

Data collection uses observation, interviews, tests, documentation, and observation of the implementation of teaching and learning syntax. The material used is the Digestive System.

Measurement of critical thinking skills and metacognitive skills uses tests in the form of pre-tests and post-tests, which are adjusted to each assessment rubric. Before conducting data analysis, normality and homogeneity tests were performed. The normality test employed the one-sample Kolmogorov-Smirnov test, while the homogeneity test was conducted using Levene's test. The data obtained in this research pertain to critical thinking skills and metacognitive skills. The data analysis process uses analysis of covariance (ANCOVA) using SPSS version 26.

RESULTS AND DISCUSSION

Experimental class and control class learning activities were carried out with a duration of 6 learning hours (JP) for the digestive system material. The percentage of learning syntax implementation in the experimental class was 100% while in the control class it was 95%. This indicates that the learning activities were conducted effectively.

The implementation of the experimental class learning syntax was 100%, assessed by three observers (1 biology teacher at Pakusari State High School and 2 students who accompanied them during the lesson). The control class has a success rate of 95%, as assessed by three observers. The difference in implementation percentage is caused by certain aspects. The experimental class meets all aspects so the percentage is 100%. The control class only reached 95% because several aspects were not implemented, such as the teacher not explaining the learning objectives at the student orientation stage, and there being no reflection or evaluation of material by the teacher in analyzing and evaluating the problem-solving process.

This research aims to evaluate the effect of the Quantum Teaching learning model based on Augmented Reality on critical thinking skills and metacognitive skills in Class XI SMA students. Quantum Teaching is a learning model that actively involves students in the learning process, with the main principle "Bring Their World into Our World, and Bring Our World into Their World". The goal is to create a learning environment that is supportive, enjoyable, and that builds emotional relationships between teachers and students (Yeniverawatiwote, 2020).

Quantum Teaching model is supported by Augmented Reality technology, which combines the virtual world with the real world. Augmented Reality makes learning more interesting and easier for students to understand (Rahayu et al ., 2022). Assemblr Edu, an application that utilizes 3D technology and Augmented Reality to create more interactive, collaborative, and interesting learning activities (Dewi et al., 2022). This application provides advantages in the form of attractive image displays, making it easier for teachers to focus, and increasing student motivation.

Using Assemblr Edu as an alternative to torsos in Quantum Teaching learning also overcomes the constraints of cost, time, and place (Oktaviana et al., 2022). Although it has disadvantages, such as a relatively large storage space and limited features, the solution involves dividing groups to overcome storage constraints and adding additional images to optimize the available features.

The food digestive system material is studied by class XI high school students. The material on the digestive system is quite challenging for students. Based on research conducted by Sari et al.,(2022), factors causing these difficulties include too much Latin reaching 88.01%; difficulty understanding material from the school handbook 81.09%; 67.60% of the teacher's explanation was not understood; lack of books from other sources 61.42%; lack of learning media 60.11%; and the material seems abstract 53.75%. The Quantum Teaching and Learning model, combined with

Augmented Reality-based media, can reduce the percentage of student difficulties because it provides effective learning strategies. So there is an increase in the percentage graph of students' abilities in critical thinking skills and metacognitive skills.

Critical Thinking Skills

Data on students' critical thinking skills scores were obtained through tests given, namely in the form of a pretest and a posttest. The test aims to determine the effect of the Augmented Reality-based Quantum Teaching learning model on students' critical thinking skills. The pretest and posttest consist of 5 questions, which are arranged based on critical thinking indicators initiated by Ennis in 1987.

According to Ennis (1987) there are five indicators of critical thinking skills, namely providing simple explanations, building basic skills, providing further explanations, concluding, and developing strategies and tactics. Critical thinking has five main aspects, namely, practicality, reflection, reasonableness, belief, and action (Martiani et al., 2021). The aim of this research is to measure the influence of the Quantum Teaching learning model based on Augmented Reality on the critical thinking abilities of class XI students.

The following chart (Figure 1 and 2) summarizes the percentage of critical thinking skills as measured by the pretest results for the experimental and control classes.

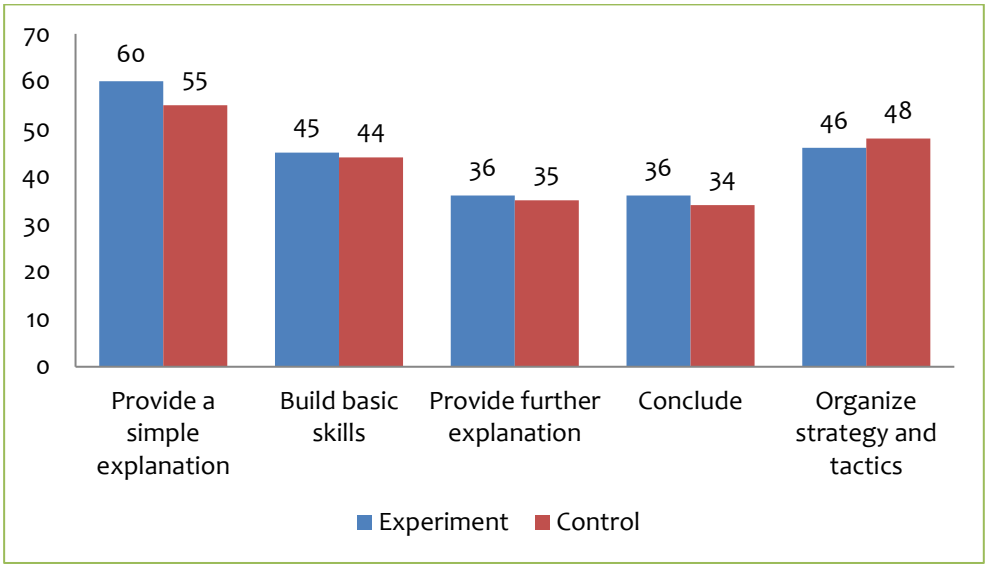

Figure 1. Graph of the results of the average pretest score for critical thinking skills

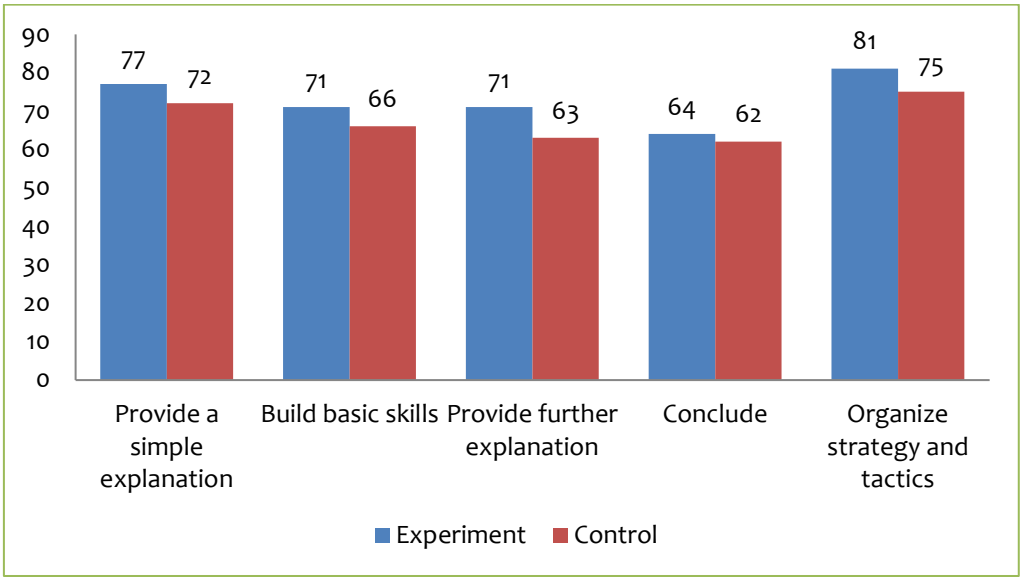

Figure 2. Graph of the results of the average posttest score for critical thinking skills

The research results indicate that the Quantum teaching model, based on Augmented Reality using Assemblr Edu, has a positive impact on students' critical thinking skills. These results are proven by ANCOVA analysis which shows a sig value of 0.000 which means less than 0.05. Critical thinking is a reflective thinking ability that focuses on decision-making patterns regarding what to believe, what to do, and what can be accounted for (Ennis, 1987). Critical thinking skills are one of the important aspects that students need in the learning process (Safarati & Zuhra, 2021). Critical thinking skills are very important because individuals who have these abilities are able to carry out logical analysis, solve problems effectively, and make rational decisions based on a mature understanding of a situation or something they believe in (Susilawati et al., 2020).

The research results showed that, before being given treatment, the percentage of critical thinking abilities among students in the experimental and control classes was not significantly different. However, after implementing Quantum Teaching based on Augmented Reality, the experimental class showed significant improvement compared to the control class. The average critical thinking skills score is also higher in the experimental class due to the different learning approach. The use of Assemblr Edu in Quantum Teaching enables students to project digestive system organs in three dimensions, replacing the need for digital torsos. This is supported by the opinion of Rahma et al., (2023) The use of imaginative, creative, useful, and efficient learning resources plays a very important role in the learning process.

Table 2 shows the frequency distribution of critical thinking skills test results with a total of 36 students in each class. The table shows the average value of each indicator in the experimental and control classes. The increase in critical thinking skills is evident through the difference in value. The experimental class got an increase in score of 141, while the control class only got 122. The test results showed that the experimental class outperformed the control class. However, these results show that the highest increase in the experimental class was in the indicator, providing further explanation and setting a strategy of 35. Meanwhile, the lowest increase in the experimental class was in the indicator, providing a simple explanation of 17. Then for the control class, the highest increase was in the indicator providing further explanation and the concluding indicator, both of it was 28. Meanwhile, the lowest increase was in the indicator, providing a simple explanation of 17.

Table 2. Frequency Distribution of Critical Thinking Skills Test Results

No.	Critical Thinking Indicators	Experimental Class average score		Difference	The average value of the control class		Difference
		Pretest	*Posttest*		*Pretest*	*Posttest*	
1.	Provide a simple explanation	60	77	17	55	72	17
2.	Build basic skills	45	71	26	44	66	22
3.	Provide further explanation	36	71	35	35	63	28
4.	Conclude	36	64	28	34	62	28
5.	Set strategy and tactics	46	81	35	48	75	27
	Total			141			122

Pretest and posttest scores on each indicator show an increase in students' critical thinking abilities. The experimental class experienced a greater increase in scores than the control class, specifically a 19-point increase. These results support the view that Quantum Teaching based on Augmented Reality is effective in improving students' critical thinking abilities (Safarati & Zuhra, 2021). This is because, in the Quantum Teaching learning model, students do not just memorize; they are encouraged to seek their own knowledge from new information, rather than just receiving knowledge from the teacher.

Data on students' critical thinking skills scores were then analyzed using a normality test, which was carried out using the Kolmogorov-Smirnov test. The Kolmogrov-Smirnov monte Carlo results show a Sig value of 0.180, which indicates that the Sig value is greater than 0.05, meaning the data is normally distributed. Next, a homogeneity test was carried out in both classes using Levene's Test. The homogeneity results yield a significance value of 0.122, indicating that the significance value is greater than 0.05, which means the data is homogeneous. Normality and homogeneity tests are two prerequisite tests conducted before performing hypothesis testing. In the prerequisite test, namely the normality test, the result is that the test data is normally distributed, so that the hypothesis test is carried out using a parametric statistical test, namely the ANCOVA test.

Table 3. Hypothesis Test Results for Critical Thinking Skills

Class	N	Average				F	Sig.(2-tailed)
		Pretest	Std. Deviation	*Posttest*	Std. Deviation		
Control	36	43.11	8.924	70.08	12.749	91.091	0.000
Experiment	36	44.81	8.444	72.61	9.178		

The results of hypothesis testing using SPSS Statistics 26 show a Sig. (2-tailed) pretest posttest value of 0.000, which means less than 0.05, meaning that Ho, which says there is no influence of the Augmented Reality-based Quantum Teaching learning model on critical thinking skills, is rejected. Therefore, it can be concluded that the Quantum Teaching-based learning model, combined with Augmented Reality, has an influence on the digestive system material and the critical thinking skills of class XI biology students.

Indicators that experienced significant improvement in the experimental class were providing further explanations and developing strategies and tactics. This is caused by the use of

quizzes in learning, which affects students' ability to seek alternative solutions and determine effective actions. Quantum Teaching has a "name" stage, which helps convey concepts, develop thinking skills, and learning strategies through providing keywords, concepts, models, formulas, and input (Nasir & Amri, 2023).

Even though the results show an increase in critical thinking skills, research shows the need for more optimal learning to improve these skills (Oktasari & Saputri, 2021). Wijayanti & Siswanto (2020) It was also stated that students' critical thinking abilities are still not optimal, possibly due to a lack of training on indicators of critical thinking abilities and insufficient learning opportunities that encourage students' abilities in this regard. In this context, the role of teachers becomes crucial in educational innovation, as it aims to improve students' critical thinking abilities.

Metacognitive Skills

Data on students' metacognitive skill scores were obtained through tests given, namely in the form of a pretest and a posttest. The test aims to determine the effect of the Augmented Reality-based Quantum Teaching learning model on students' metacognitive skills. The pretest and posttest consist of three questions arranged based on metacognitive indicators, as initiated by Schraw and Dennison in 1994. The following chart, Figures 3 and 4, provides a summary of the percentage of metacognitive skills as indicated by the pretest results for the experimental and control classes.

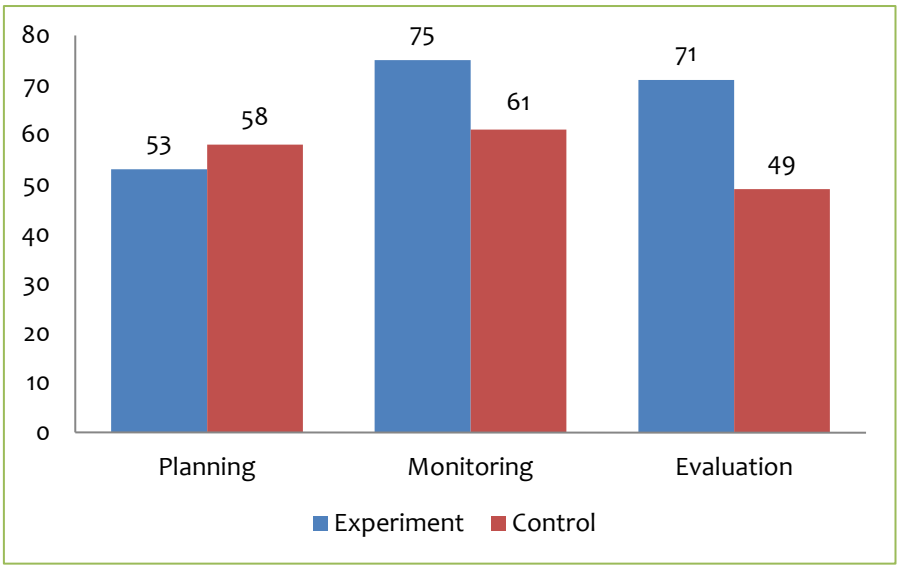

Figure 3. Graph of the average percentage of pretest score for metacognitive skills

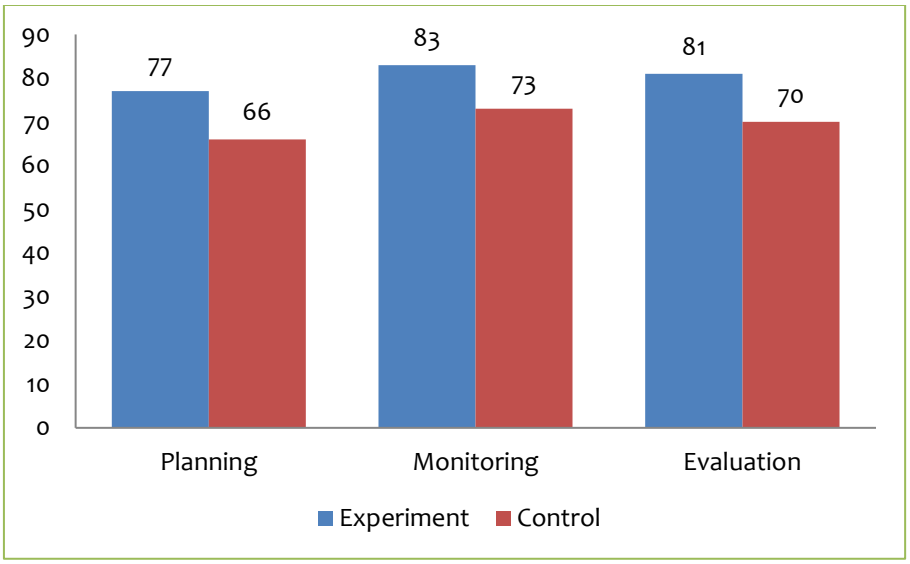

Figure 4. Graph of the average percentage of posttest scores for metacognitive skills

Table 4 shows the frequency distribution of metacognitive skills test results with a total of 36 students in each class. The table shows the average value of each indicator in the experimental and control classes. The increase in metacognitive skills results is not significantly different between the experimental and control classes, differing by only 1 value. The experimental class saw an increase in score of 42, while the control class increased by 41. The test results showed that the experimental class was slightly superior to the control class. However, these results show that the highest increase in the experimental class was in the planning indicator of 24. Meanwhile, the lowest increase in the experimental class was in the monitoring indicator of 8. Then, for the control class, the highest increase was in the evaluation indicator of 21. Meanwhile, the lowest increase was in the planning indicator of 8.

Table 4. Frequency Distribution of Metacognitive Skills Test Results

No.	Metacognitive Skills Indicators	Experimental Class average score		Difference	The average value of the control class		Difference
		Pretest	*Posttest*		*Pretest*	*Posttest*	
1.	Planning	53	77	24	58	66	8
2.	Monitoring	75	83	8	61	73	12
3.	Evaluation	71	81	10	49	70	21
	Total			42			41

Data on students' metacognitive skills scores were then analyzed using a normality test, which was carried out using the Kolmogorov-Smirnov test. The Kolmogrov-Smirnov monte Carlo results show the Sig value. 0.136, which means the Sig value greater than 0.05 means the data is normally distributed. Next, a homogeneity test was carried out in both classes using the Lavene's Test. The homogeneity results yield a significance value of 0.080, which indicates that the significance value is greater than 0.05, indicating that the data is homogeneous. Normality and homogeneity tests are two prerequisite tests that must be conducted before performing hypothesis testing. In the prerequisite test, namely the normality test, the result is that the test

data is normally distributed so that the hypothesis test is carried out using a parametric statistical test, namely the ANCOVA test.

Table 5. Hypothesis Test Results for Metacognitive skills

Class	N	Average				F	Sig.(2-tailed)
		Pretest	Std. Deviation	*Posttest*	Std. Deviation		
Control	36	59.06	8.187	74.25	9.160	48.506	0.000
Experiment	36	63.64	6.160	80.31	9.528		

The results of hypothesis testing using SPSS Statistics 26 show a Sig. (2-tailed) pretest posttest value of 0.000, which means less than 0.05, meaning H0, which says there is no influence of the Quantum Teaching-based learning model. Augmented Reality Has No Impact on Metacognitive Skills. Therefore, it can be concluded that the Quantum Teaching-based learning model, combined with Augmented Reality, has an influence on the digestive system material and the metacognitive skills of class XI biology students.

Quantum Teaching Learning Model Based on *Augmented Reality* on Digestive System Material on the Metacognitive Skills of High School Students

The research results indicate that the Quantum teaching model, based on Augmented Reality using Assemblr Edu, has a positive impact on students' metacognitive skills. These results are proven by ANCOVA analysis which shows a sig value 0.000 which means less than 0.05. Critical thinking skills are closely related to metacognitive skills, namely the ability to understand, control, and regulate one's own thinking processes. According to Suharyani et al., (2023) metacognition includes awareness of what we know and don't know, understanding effective strategies in solving problems, and the ability to monitor and evaluate our own thinking processes.

This research aims to determine the effect of the Quantum Teaching learning model based on Augmented Reality on the metacognitive skills of class XI students. The difference between the pretest and posttest scores for each indicator shows an increase in metacognitive skills, with the experimental class increasing by 42 points and the control class by 41 points. Although the difference is small, a significant increase occurred in the experimental class on the planning indicator by 24 points.

The cause of this significant increase can be explained by the TANDUR-based Quantum Teaching stages. In the "Grow" stage, students are guided to get to know themselves through questions and including learning objectives that are relevant to everyday life (Nasir & Amri, 2023). The "Natural" stage enables students to learn directly through Augmented Reality media, understand the structure of the digestive system, and enhance their metacognitive abilities. The "Name" stage encourages students to give names to biological concepts (Lekatompessy et al ., 2020) . Meanwhile, the "Demonstration and Repeat" stage helps strengthen cognitive processes and repetition of material (Yunus & Rismawati, 2023) . The "Celebrate" stage of students' work also helps maintain interest in learning, which ultimately improves students' metacognitive skills.

The higher average experimental class score was driven by the use of the Quantum Teaching model based on Augmented Reality with the Assemblr Edu application. Augmented Reality media has great potential to increase student interest, inspiration, and motivation. The use of this media

in biology learning provides positive feedback, allows students to be actively involved, and increases understanding of the material (Cai et al., 2020).

Increasing students' metacognitive skills aligns with technological developments and students' learning interests (Jesionkowska et al., 2020). Augmented Reality media plays a crucial role in providing realistic learning experiences and motivating students to be actively engaged in the learning process. Thus, Augmented Reality-based Quantum Teaching is considered effective in improving students' metacognitive skills, providing evidence that this model can have a positive impact on biology learning.

CONCLUSION

Based on the research results and discussions described, it can be concluded that the Quantum Teaching Learning model, based on Augmented Reality, has an effect on the critical thinking skills of class XI high school students regarding the digestive system. Besides that, it can be concluded that the Quantum Teaching learning model, which is based on Augmented Reality, has an influence on the metacognitive skills of class XI high school students regarding the digestive system.

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