JPPIPA 10(8) (2024)

Jurnal Penelitian Pendidikan IPA

Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Boosting Critical Thinking with STEM-Based Nanolearning in Reaction Rate Studies

Arya Girald Baihaqie[1], Dedeh Kurniasih[1*], Rizmahardian A. Kurniawan[1], Zahratun Nufus[2]

[1] Department of Chemical Education, Faculty of Education, Universitas Muhammadiyah Pontianak, Pontianak, Indonesia.
[2] SMAIT AL-Fityan, Kubu Raya, Indonesia.

Received: April 18, 2024
Revised: June 28, 2024
Accepted: August 25, 2024
Published: August 31, 2024

Corresponding Author:
Dedeh Kurniasih
dedeh.kurniasih@unmuhpnk.ac.id

DOI: 10.29303/jppipa.v10i8.8303

Abstract: This study aims to determine the effect of STEM-based Nanolearning implementation in improving students' critical thinking skills at SMAIT Al-Fityan Kubu Raya. This study used a one-group pre-test-post-test quasi-experimental research design. The population in this study consisted of 59 people. The sample selection for this study was carried out using purposive sampling, specifically targeting 19 students from class XI Ikhwan at SMA IT Al-Fityan Kubu Raya. The data collection technique used was a critical thinking skills test, which includes four indicators: interpretation, evaluation, analysis, and explanation. The results of the pretest research obtained at 35.53 were categorized as low and the posttest obtained at 82.89. Data analysis was conducted using normality test pretest sig 0.062 and posttest 0.070 normally distributed, hypothesis test obtained sig 0.00 <0.05, H_1 accepted, and effectiveness test resulted in N-gain value of 0.75. This shows that Nanolearning has a significant effect on critical thinking skills of class XI Ikhwan SMA IT Al - Fityan Kubu Raya.

Keywords: Critical thinking; Nanolearning; Reaction rate; STEM

Introduction

In the age of 21st century learning, critical thinking skills are essential for students. These skills can even be considered the most crucial pillar needed, surpassing other skills in importance (Alsaleh, 2020; Halim & Halim, 2024; Sujanem et al., 2022; Taqiyyah et al., 2023; Wiratman et al., 2023). Critical thinking skills enable students to study problems systematically and structurally (Suryawan et al., 2023). With these skills, they can tackle various obstacles in an organized manner. Additionally, critical thinking empowers students to formulate innovative and solution-oriented questions when confronting issues (Carter et al., 2018). Having critical thinking skills benefits students by enabling them to understand the learning material more easily (Mahdian et al., 2024). One of the subjects that requires critical thinking skills is chemistry (Riti et al., 2021).

Kinetics is one of the important learning topics in chemistry, which required three areas of representation: macroscopic, microscopic, and symbolic aspects (Ishma & Novita, 2021; Juwitasari & Suyono, 2023; Priliyanti et al., 2021). These three representations require students to possess a higher level of thinking, specifically critical thinking skills (Ihsan et al., 2019; Sukmawati, 2019). In reality, students lacked of critical thinking skills when studying reaction kinetics, as evidenced by the low learning outcomes (Kirik & Boz, 2012; Setianingsih & Roshayanti, 2022). This situation occurs because students experience boredom with teaching methods that rely solely on simple question-and-answer sessions. Additionally, the students were less motivated and curious about the subject (Dewi et al., 2020).

Mathematical calculations and physical chemistry are among the challenges in studying reaction rate material (Auliyani et al., 2023; Seery, 2019). Students often face some difficulties in learning chemistry, especially in distinguishing between thermodynamics

How to Cite:
Baihaqie, A. G., Kurniasih, D., Kurniawan, R. A., & Nufus, Z. (2024). Boosting Critical Thinking with STEM-Based Nanolearning in Reaction Rate Studies. *Jurnal Penelitian Pendidikan IPA*, *10*(8), 6132–6141. https://doi.org/10.29303/jppipa.v10i8.8303

and kinetics. They often have difficulty distinguishing between these two concepts. Another common misconception is that the reactant exponents in the reaction rate law are often mistakenly thought to be directly related to the stoichiometric coefficients of the reactants in the equilibrium reaction equation. In addition, understanding catalyst mechanisms as well as the overall concepts of reaction rate and activation energy is also a significant challenge (Gegios et al., 2017). Students often do not understand the relationship between the order of response and temperature and its relationship to the value of the constant. Furthermore, they frequently fail to grasp the connection between temperature and activation energy (Bain et al., 2019). Furthermore, the conventional teaching method, which relies solely on simple question-and-answer sessions, causes students to feel bored and unmotivated, and it fails to spark their curiosity about the subject of reaction rates (Dewi et al., 2020). Furthermore, the conventional teaching method, which relies solely on simple question-and-answer sessions, causes students to feel bored and unmotivated, and it fails to spark their curiosity about the subject of reaction rates (Wibowo et al., 2023).

Nanolearning is a term that describes a method of delivering educational content in a short period of time, usually through short videos or multimedia formats (Aburizaizah & Albaiz, 2021; Garcia & Yousef, 2023; Solihin et al., 2021). Nanolearning can be a solution for 21st-century learners among generation X and Z, as it can accommodate students' long study hours (Karlen et al., 2019; Wibowo et al., 2023). Fast and entertaining content provides information that grabs learners' attention (Marks, 2021).

Nanolearning is highly focused and designed to assist learners in understanding specific topics through smaller inputs in a short amount of time (Karlen Gramming et al., 2019). Nanolearning will be more effective if combined with a learning approach; one such approach that can be applied and complements Nanolearning is the STEM approach (Gao et al., 2020). STEM learning is a method that integrates four branches of science in the learning process with the aim of encouraging students to develop critical thinking skills. The four disciplines in the STEM approach consist of science, technology, engineering and math (Febrianti et al., 2022; Utami et al., 2022). The interconnection between these fields of study facilitates students' comprehension of the material. Furthermore, the STEM approach can enhance students' critical thinking skills in learning about reaction rates, resulting in an average student score of 95% (Amarlita, 2023).

Most of the previous research on nano-learning focuses on the idea and how it can be used in education as a whole. However, until now there has been no research that specifically applies nano-learning in schools, especially in chemistry subjects in senior high schools. In addition, there are no studies that combine nano-learning with other learning methods or that evaluate how effective nano-learning is in improving students critical thinking skills (Ansari et al., 2023; Pham et al., 2023; Radzitskaya & Islamov, 2024; Vivekananth, 2022).

This research focuses on combining nanolearning concept with STEM approach which is still rarely explored in the context of education in Indonesia, especially in chemistry. The main objective is to provide an innovative and adaptive learning model to improve students' critical thinking skills. In addition, this research aims to provide new insights related to the implementation of technology in learning that can be adopted by various educational institutions. In conclusion, by examining STEM-based nano-learning, this research has the potential to open new avenues towards more efficient and effective education in developing essential 21st century skills, particularly critical thinking skills.

At present, there is insufficient research data available on the utilization of Nanolearning-STEM in chemistry classrooms to explore the subject of reaction rates. Therefore, this study must be conducted. The aim of this research was to assess the effects of implementing Nanolearning-STEM in helping scholars' critical thinking skill chops in chemistry assignments, especially on response rate material.

Method

Place, Time and Type of Research

This study was a quasi-experiment utilizing a one-group pretest-posttest design. A pretest was conducted prior to the application of the Nanolearning STEM lessons, followed by a posttest after the application of STEM-based Nanolearning. The research design is illustrated in Table 1 (Sakdiah et al., 2022).

Table 1. One-Group Pretest-Posttest Design

Group	Pretest	Treatment	Posttest
Experiment	O_1	X	O_2

Description:

O_1: The pretest is conducted prior to administering the treatment

X : Treatment is given to the students

O_2: The post-test is conducted after the treatment has been administered

Research Population and Sample

The population in this study were grade XI students at SMAIT Al-Fityan Kubu Raya in the 2023/2024 school year, numbering 59 people. The sample used in this study consisted of 19 grade XI students from the Ikhwan class at SMAIT Al-Fityan. The sample selection process was carried out by following the school regulations set using purposive sampling method.

Data Collection Technique

Data for this study was collected using a test consisting of four essay questions that assessed critical thinking skills including interpretation, analysis, conclusion, and explanation (Facione, 2023).

Data Analysis Technique

Researchers perform calculations to answer the formulation of the problem and then test the hypothesis (Wulandari, 2018). The data analysis techniques used are used are prerequisite material tests, creative thinking skills tests.

Test Prerequisite Material

Normality Test

The researchers conducted a normality test on the pretest and posttest data to determine whether the samples followed a normal distribution or not, using the Shapiro-Wilk statistical test.

Hypothesis Testing

Once the data was confirmed to be normally distributed, the researcher performed hypothesis testing using a paired samples t-test. If the two-tailed significance value is less than 0.05, the null hypothesis (H_0) is rejected, and the alternative hypothesis (H_1) is accepted (Alvionita et al., 2020). Conversely, the null hypothesis (H_0) is accepted and the alternative hypothesis (H_1) is rejected if the significance value (2-tailed) is greater than 0.05.

Effectiveness Test

The researchers used the effectiveness test to determine whether the given treatment had any impact. The formula is (Melisa et al., 2024).

$$g = \frac{s_f - s_i}{maximum\ skor - s_i} \quad (1)$$

The g value is the normalized gain (n-gain), which is used to measure the improvement of learning outcomes. The posttest score is denoted by s_f, while the pretest score is denoted by s_i. These two scores are used to calculate the N-gain, which helps determine the effectiveness of the Nanolearning method.

Calculating N-gain based on pretest and posttest scores, they can classify the improvement into three categories: high, medium, and low. The high category indicates that the improvement in learning outcomes is very significant (N-gain > 0.7), the medium category indicates a moderately significant improvement (0.3 ≤ N-gain ≤ 0.7), and the low category indicates a less significant improvement (N-gain < 0.3) (Kurniawan & Hidayah, 2020).

Result and Discussion

Result

Data from the pretest and posttest were also analyzed and distributed according to the critical thinking skills assessment criteria (Almunawarah et al., 2023). Based on the research data, the average pretest score was 35.53, categorized as low, whereas the average posttest score was 82.89, categorized as good. At the pretest stage, most participants scored between 31.25 and 43.75. However, after participating in STEM-based Nanolearning, overall, participants tended to achieve scores ranging from 81.25 to 93.75 in the posttest assessment.

The average score of students using Nanolearning with a focus on STEM subjects increased by 47.36 points. The data shows that the implementation of STEM-focused Nanolearning in chemistry lessons, especially in the context of the reaction rate topic, has the potential to enhance students' critical thinking skills. The difference in average scores can be seen in Figure 1.

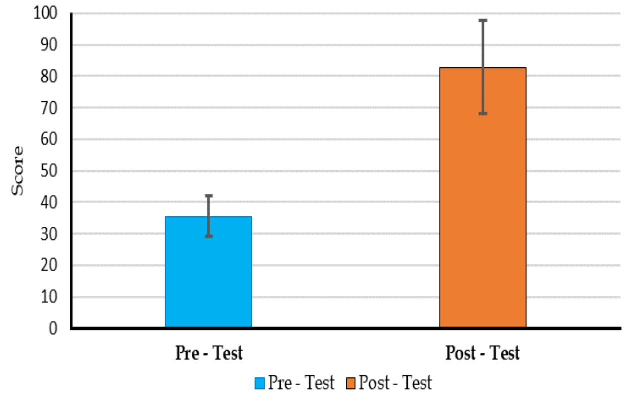

Figure 1. Graph of pre-test and post-test scores of students critical thinking skills

According to the study's findings, the data obtained were subjected to various statistical tests using SPSS version 29.0 software, including normality tests and hypothesis testing. Additionally, this research also involved testing the effectiveness of the method used and evaluation using a critical thinking skills test sheet.

This test sheet summarizes important indicators of critical thinking skills, of interpretation, analysis, reasoning, and explanation (Facione, 2023).

Normality Test

The Shapiro-Wilk test method was employed to conduct the normality test. The test results indicated a significance value of 0.62 for the pretest, which is greater than 0.05 (0.62 > 0.05), demonstrating that the pretest data follows a normal distribution. The significance value of the post-test data is 0.70, exceeding the threshold of 0.05, suggesting that the post-test data follows a normal distribution as well. It can be inferred from this information that the pretest and posttest data exhibit a normal distribution. The outcomes of the normality test for the pretest-posttest can be observed in Table 2.

Table 2. Pretest-Posttest Normality Test Results

	Kolmogorov-semirnov			Shapiro – wilk		
	Statistic	df	Sig.	statistic	df	Sig.
Pretest	.181	19	.101	.906	19	.062
Posttest	.199	19	.047	.909	19	.070

Hypothesis Testing

Hypothesis testing was conducted using the paired t-test. The test results (2-tailed) indicate a value of 0.001, which is smaller than 0.05 (0.001 < 0.05), thus leading to the conclusion that H_1 is accepted and H_O is rejected (Table 3). Therefore, STEM-based Nanolearning has a significant has influence on improving students' critical thinking skills.

Table 3. Paired t-Test

Pre-test	Mean	Std. deviation	Std. Error men	Lower	Upper	t	df	One side	Two side
Post-test	-47.36	14.77	3.39	-54.49	-40.24	-13.97	18	<.001	<.001

Effectiveness Test

The effectiveness was evaluated using the N-gain test. The results indicate an N-gain value of 0.72, which falls into the high category. From these results, it can be concluded that STEM-based Nanolearning applied to reaction rate material for class XI Ikhwan School students at SMAIT Al-Fityan Kubu Raya very effective in improving students' critical thinking skills in understanding the material. N-gain test results can be seen in Table 4.

Table 4. N-gain Value Category

	N	Minimum	Maximum	Mean
N-gain score	19	.33	1.00	.72
N-gain persen	19	33.33	100.00	72.37
Valid N	19			

Discussion

Critical Thinking Skills

Researchers administered pretest and posttest essay questions that had been validated by experts. Critical thinking skills encompass four indicators: interpretation, analysis, evaluation, inference, and explanation (Facione, 2023). The score calculation for each indicator is based on students' answers to each question. The outcomes of the calculations for each indicator of students' critical thinking skills are presented in Figure 2.

The graph shows a significant overall rise in the scores of all four critical thinking skill indicators. The results of the descriptive analysis showed that students' pretest and posttest mean scores increased in terms of critical thinking skills. A paired sample t-test was conducted to confirm this improvement. These tests were employed to further examine the observed enhancement in critical thinking skills.

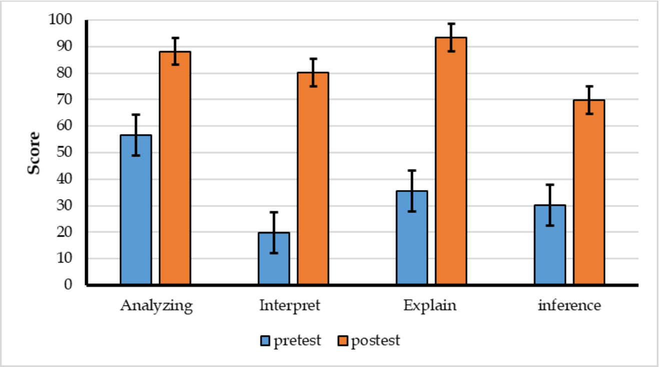

Figure 2. Percentage of critical thinking pretest and posttest for each indicator

Indicators for critical thinking skills demonstrated varying levels in -improvement, with the "explanation" indicator exhibiting the most significant average enhancement, while the "reasoning" indicator displayed the least progress. To measure the improvement of critical thinking skills, the G-gain value was calculated, which reflects the magnitude of the difference between the initial and final test results. The N-gain value on each indicator of critical thinking skills can be seen in Table 5.

Table 5. Critical Thinking Skills N-Gain Score for Each Indicator

KBK Indicators	Average Value Pretest	Average Value Posttest	N-gain Score	Criteria
Analyze	56.57	88.15	0.72	High
Interpret	19.73	80.26	0.75	High
Explain	35.52	93.42	0.89	High
Inference	30.26	69.73	0.56	Medium

Analyze

When evaluating the indicator analysis, the evaluation is based on pretest and posttest questions in the form of an explanation of how the phenomenon occurred. In the pretest, the obtained score was 56.57%. After implementing STEM-based Nanolearning, the posttest score increased to 88.15%. This 31.58% increase in the analysis indicator is attributed to the deeper conceptual understanding acquired by students through the learning process experience applied in STEM-based Nanolearning.

Interpret

In terms of interpretation, assessment was conducted using pretest and posttest essay questions that asked students to express their understanding of the concepts stated in each problem or question. In the pretest stage, students demonstrated a comprehension level of 19.73. After participating in Nanolearning – STEM instruction, students' posttest scores increased to 80.26%. The 60.53% improvement in the interpretation indicator is attributed to a deeper conceptual understanding gained by students through the experiential learning process of solving problems presented in Nanolearning – STEM instruction.

Explain

The indicator of the ability to explain is the ability to explain and argue logically based on the information obtained, which is an indicator of problem solving competence. This indicator is evaluated through pretest and posttest essay questions, where students are asked to explain and provide logical arguments for conclusions drawn from a given problem. In the pretest stage, students scored 35.52. After undergoing STEM-based Nanolearning, the posttest score increased to 93.42, indicating a 57.9 increase in the analysis indicator. This improvement is due to students gaining a deeper understanding of concepts through the STEM-based Nanolearning experience, including formulating arguments and drawing conclusions from the information provided.

Inference

Reasoning ability is the ability to interpret information logically and reasonably based on measurement results. This indicator is evaluated through pretest and posttest open-ended questions that require students to formulate hypotheses and draw conclusions. The indicators were analyzed using pretest and posttest questions in the form of essays where students were asked to formulate hypotheses and draw conclusions. At the pretest stage, the score achieved was 30.26. After the introduction of STEM-based Nanolearning, the score on the posttest increased to 69.73%.

Nanolearning has a positive impact on stimulating the brain to enhance critical thinking skills through the exploration and application of new knowledge. The presentation of educational content in short durations helps students to focus better, making it easier to analyze, interpret, explain, and conclude information. Additionally, in a fast-paced world with abundant information, nanolearning is essential for continuously honing and sharpening students' critical thinking abilities, so that student skills in the process of educational activities can occur optimally (Radzitskaya & Islamov, 2024). Nanolearning will enable the planning and restructuring of instructional strategies. It is one of the innovative solutions designed to assist students who struggle with fast-paced learning. Academic institutions must envision a future where education is accessible to everyone. By adopting methods like nano-learning, education can become more efficient, effective, and engaging (Kayalar, 2021).

Implementation of Stem-Based Nanolearning on Classroom Activities

In the learning process, researchers apply Nanolearning. In the core activity stage, the first syntax conducted is to plan the learning objectives. At this stage, researchers and participants jointly select the topic and material to be learned. Researchers choose material related to the issue of global warming caused by excessive use of freon. In the second syntax, researchers determine the skills to be learned, which is to create a two-minute instructional video about the process of global warming due to the use of freon generated by refrigerators. In the third syntax, researchers design strategies to achieve these skills using a STEM approach, where students are asked to design a refrigerator-making project using the Coolgardie safe technique. In the fourth syntax, the media used is a short instructional video about global warming caused by freon in refrigerators. And in the fifth stage, skill activities are disseminated across various platforms, where students upload experiment results in the form of PowerPoint presentations to the classroom platform. Implementation of STEM-based Nanolearning can be seen in Table 6

Table 6. Implementation of STEM-based Nanolearning

Nanolearning Components	STEM Components	Implementation of STEM-based Nanolearning
At this stage of learning, the chosen educational content focuses on reaction rate, specifically exploring the factors influencing the rate of reactions.	Science, students analyze learning materials using learner worksheets (LKPD) and a short 2-minute learning video.	Students discuss and analyze the Learner Worksheet (LKPD) and the singakat learning video which contains learning materials that are carried out scientifically and contextually.
Skills, at this stage the skills that will be carried out are the process of making a simple refrigerator using the cool gardie safe technique.	Technology, students make a simple refrigerator using the cool gardie safe technique.	Make a simple refrigerator with cool gardie safe technique based on work procedures properly and correctly.
Strategy, at this stage the strategy that will be used by teachers and students in achieving skills is the STEM approach.	Enggineer (Engineering), students design a simple refrigerator using the Coolgardie safe technique.	Applying STEM-based Nanolearning in the construction of a simple refrigerator using the Coolgardie safe technique.
Media, at this stage students use text media and single-length learning videos.	Mathematics, students analyze the results of experimental data and calculation results in the Learner Worksheet (LKPD).	Students present and communicate the results of experiments and calculations contained in the Learner Worksheet.
STEM-based Nanolearning activities are disseminated on various platforms, where students upload the results of experiments and calculations in the form of power point presentations to the classroom platform		

Science

In this aspect, students analyze problems related to the concept of reaction rates, such as collision theory and the factors that affect reaction rates in everyday applications. Consequently, students apply critical thinking skills by gathering various pieces of information, classifying the problems they encounter, predicting outcomes, and drawing conclusions. This process allows students to build knowledge independently and seek solutions to the issues they identify from a case study.

The application of scientific aspects in teaching reaction rates is implemented through the provision of case studies in student worksheets (LKPD) and short-duration educational videos. Working in groups, students comprehend, discuss, and analyze the phenomena presented in these case studies by utilizing various scientific sources and literature. The science process can be shown in Figure 3.

Figure 3. Implementation of science aspects

Engineering

On the Engineering aspect, students design simple experiments that train them to predict the factors affecting the speed of reaction rates and to think critically when analyzing information. In this experiment, students learn that temperature affects the rate of reaction: As the temperature increases, the reaction rate accelerates, while a decrease in temperature slows the reaction. From an engineering perspective, this activity is related to enhancing students' creativity and fostering technological innovation. In this study, students were divided into four groups to design simple experimental tools that demonstrate the factors influencing reaction rates. In a simple laboratory experiment conducted by students, they construct a basic refrigerator using the Coolgardie safe technique, with temperature being the primary variable affecting the reaction rate. The experiment involves utilizing the cool air generated by wetting a hessian sack. Subsequently, the learners employ a thermogun to measure the temperature before and after the process, and a stopwatch to observe the time required for these temperature changes. Following the experiment, the students analyze their findings and elucidate the factors influencing the reaction rate, as well as the products yielded from the experiment. The engineering process can be shown in Figure 4.

Figure 4. Implementation of engineering aspects

Technology

In the context of technology, the application of technology in responsive learning is to show a short video as a form of Nanolearning about the effects of global warming through the use of Freon. This encourages students to think critically in seeking solutions. Through this approach, students gain an understanding of refrigerator production using Coolgardie safe techniques and its relationship with temperature regulation to preserve food by lowering the temperature, thus reducing reaction rates. They also learn to calculate reaction times using a stopwatch as a necessary comparison tool in their experiments.

In the activity of making refrigerators using the Coolgardie safe technique, students were divided into three groups, each consisting of 6 to 7 individuals. One group failed because they used main raw material that was not suitable, namely quite thin wood. Meanwhile, the other two groups succeeded because they used thick enough wood as the main material and followed the manufacturing procedure correctly, resulting in refrigerators that they made standing firmly and producing cooler temperatures. Through this experience, the students gained an understanding that the use of freon, which can contribute to global warming, can be addressed by making simple refrigerators using the Coolgardie safe technique, leveraging the concept of reaction rate. The Technology process can be shown in Figure 5.

Figure 5. Implementation of technology aspect

Mathematics

In the context of mathematics, students are provided with a brief understanding of reaction rate concepts and reaction orders. Following this, they engage in calculations related to reaction rates based on data they recorded while measuring temperature on a simple refrigerator in the Student Worksheet (LKPD). Through this activity, students are tested on their ability to analyze data, perform mathematical calculations, manage information, as well as convey opinions or the results of creating a simple refrigerator and the calculations they have conducted. The student math process and the student presentation process can be seen in Figure 6.

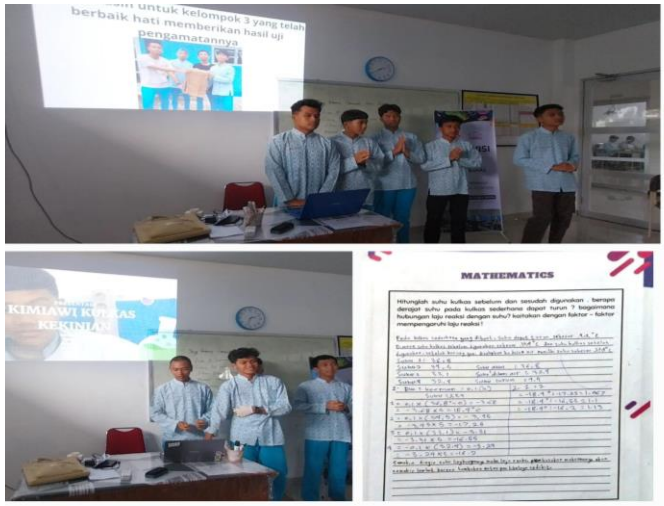

Figure 6. Implementation of mathematics aspects and student presentation process

Conclusion

Based on the results of the research conducted, it can be concluded that the application of the Nanolearning method has a significant impact on improving critical thinking skills in class XI Ikhwan students at SMA IT Al-Fityan Kubu Raya. This result shows that Nanolearning can be an effective strategy in learning to improve critical thinking skills which are very important in the world of education.

Acknowledgments

The researcher would like to thank all those who have provided assistance, especially the validators and SMAIT AL-Fityan Kubu Raya for providing the opportunity to conduct research and implement the learning strategies that have been developed in their school.

Author Contributions

Conceptualization: D, A, R, Z; Methodology: D, A, R, Z; Validation: H, Z, M, D, E; Writing research: A; Editing research data: D, A, R.

Funding

No funding from external sources.

Conflicts of Interest

No conflict of interest.

References

Aburizaizah, S. J., & Albaiz, T. A. (2021). Review of the Use and Impact of Nano-Learning in Education. *4th International Conference on Research in Education*, *4*(1), 83–93. https://doi.org/10.5281/zenodo.11273343

Almunawarah, R., Adnan, & Bahri, A. (2023). Analysis of Critical Thinking Ability on Senior High School Students in Biology Classroom Based on Modified FRISCO Indicators. *International Journal of Science and Research (IJSR)*, *12*(10), 876–882. https://doi.org/10.21275/sr231002095937

Alsaleh, N. J. (2020). Teaching Critical Thinking Skills : Literature Review. *The Turkish Online Journal of Educational Technology*, *19*(1), 21–39. https://doi.org/10.46843/jiecr.v5i1.978

Alvionita, D., Prabowo, & Supardi, I. (2020). Problem Based Learning With The SETS Method To Improve The Student's Critical Thinking Skill of Senior High School. *IJORER : International Journal of Recent Educational Research*, *1*(3), 246–260. https://doi.org/10.46245/ijorer.v1i3.46

Amarlita, D. M. (2023). Penerapan Pendekatan STEM pada Materi Laju Reaksi Siswa Kelas XI. *Journal on Education*, *5*(2), 4349–4353. https://doi.org/10.31004/joe.v5i2.1152

Ansari, T. A., Hina, H., & Khan, S. A. (2023). New Trends in Higher Education with "Nano-Learning." *International Journal of Engineering Technology and Management Sciences*, *7*(3), 381–388. https://doi.org/10.46647/ijetms.2023.v07i03.048

Auliyani, Z. F., Rery, R. U., & Noer, A. M. (2023). The Effect of E-Scaffolding in Guided Inquiry Learning on Concept Understanding in Reaction Rate Material. *Jurnal Penelitian Pendidikan IPA*, *9*(6), 4417–4422. https://doi.org/10.29303/jppipa.v9i6.3646

Bain, K., Rodriguez, J. M. G., & Towns, M. H. (2019). Investigating Student Understanding of Rate Constants: When is a Constant "constant"? *Journal of Chemical Education*, *96*(8), 1571–1577. https://doi.org/10.1021/acs.jchemed.9b00005

Carter, A. G., Creedy, D. K., & Sidebotham, M. (2018). Critical thinking in midwifery practice: A conceptual model. *Nurse Education in Practice*, *33*(17), 114–120. https://doi.org/10.1016/j.nepr.2018.09.006

Dewi, C., Utami, L., & Octarya, Z. (2020). Pengaruh Model Pembelajaran Inkuiri Terbimbing Integrasi Peer Instruction terhadap Kemampuan Berpikir Kritis Siswa SMA pada Materi Laju Reaksi. *Jurnal of Natural Sciencce*, *3*(2), 196–204. https://doi.org/10.24014/jnsi.v3i2.9100

Facione, P. A. (2023). Critical Thinking : What It Is and Why It Counts. *Insight Assessment*, *6*(11), 1–28. Retrieved from https://rb.gy/2phfko

Febrianti, F., Fajriana, F., Wulandari, W., Nuraina, N., & Herizal, H. (2022). Pengembangan Modul Matematika Dengan Pendekatan Science, Technology, Engineering, and Mathematics (Stem) Pada Materi. *Jurnal Pendidikan Matematika Malikussaleh*, *2*(2), 165–172. https://doi.org/10.29103/jpmm.v2i2.9432

Gao, X., Li, P., Shen, J., & Sun, H. (2020). Reviewing Assessment of Student Learning In Interdisciplinary STEM Education. *International Journal of STEM Education*, *7*(24), 1–14. https://doi.org/10.1186/s40594-020-00225-4

Garcia, M., & Yousef, A. M. F. (2023). Cognitive and Affective Effects of Teachers' Annotations and Talking Heads on Asynchronous Video Lectures in a Web Development Course. *Research and Practice in Technology Enhanced Learning*, *18*(20), 1–23. https://doi.org/10.58459/rptel.2023.18020

Gegios, T., Salta, K., & Koinis, S. (2017). Investigating high-school chemical kinetics: The Greek chemistry textbook and students' difficulties. *Chemistry Education Research and Practice*, *18*(1), 151–168. https://doi.org/10.1039/C6RP00192K

Halim, T., & Halim, S. (2024). Reflections on Nano Learning and Teaching : Can it Be a Substitute for Higher Education ? *Global Journal of Arts Humanity and Social Sciences*, *4*(5), 326–331. https://doi.org/10.5281/zenodo.11273343

Ihsan, M. S., Ramdani, A., & Hadisaputra, S. (2019). pengembangan e-learning pada pembelajaran kimia untuk meningkatkan kemampuan berpikir kritis peserta didik. *Jurnal Pijar Mipa*, *14*(2), 84–87. https://doi.org/10.29303/ jpm.v14i2.1238

Ishma, E. F., & Novita, D. (2021). impelementasi LKPD inkuiri terbimbing online untuk melatih keterampilan berpikir kritis materi gaktor laju reaksi. *Chemistry Education Practice*, *4*(1), 11–17. https://doi.org/10.29303/cep.v4i1.2272

Juwitasari, R. A., & Suyono. (2023). pembelajaran materi laju reaksi dengan penataan kurikuler nested untuk meningkatkan keterampilan berpikir kritis dan hasil belajar peserta didik. *Journal of Chemical Education*, *12*(1), 1–7. https://doi.org//10.26740/ujced.v12n1.p1-7

Karlen, G., Ann, C., Ejemyr, E., & Thunell, E. (2019). Implementing Nano-Learning in the Law Firm. *Legal Information Management*, *19*(4), 241–246. https://doi.org/10.1017/S1472669619000562

Karlen Gramming, A. C., Ejemyr, E., & Thunell, E. (2019). Implementing Nano-Learning in the Law Firm. *Legal Information Management*, *19*(4), 241–246.

https://doi.org/1017/s1472669619000562

Kayalar, F. (2021). Features and Applications of Nano-Learning Model. *Journal of Academic Social Resources*, *6*(32), 1922–1927. https://doi.org/10.31569/asrjournal.414

Kirik, O. T., & Boz, Y. (2012). Cooperative learning instruction for conceptual change in the concepts of chemical kinetics. *Chemistry Education Research and Practice*, *13*(3), 221–236. https://doi.org/10.1039/c1rp90072b

Kurniawan, A. B., & Hidayah, R. (2020). Efektivitas Permainan Zuper Abase Berbasis Android Sebagai Media Pembelajaran Asam Basa. *UNESA Journal of Chemical Education*, *9*(3), 317–323. https://doi.org/10.26740/ujced.v9n3.p317-323

Mahdian, Ariyanti, R., & Bakti, I. (2024). Increase Critical Thinking Skills and Learning Outcomes of Students on Buffer Solution Material Using E-Modules Based on Scientific Critical Thinking (SCT). *Jurnal Penelitian Pendidikan IPA*, *10*(1), 210–218. https://doi.org/10.29303/jppipa.v10i1.5799

Marks, J. (2021). *Let's Be Reasonable*. Princeton University Press. https://doi.org/10.2307/j.ctv15r58qj

Melisa, P., Nursamsu, & Setyoko. (2024). Pengaruh Model Pembelajaran Project Based Learning (Pjbl) Materi Plantae Terhadap Hasil Belajar Siswa Di Sma Negeri 1 Langsa. *Journal of Student Research (JSR)*, *2*(2), 202–209. https://doi.org/10.55606/jsr.v2i2.2851

Pham, X. L., Nguyen, P. N., & Nguyen, T. H. (2023). Innovative Approaches to Learning: An Examination of Nano-Learning Research. *2023 14th IIAI International Congress on Advanced Applied Informatics (IIAI-AAI)*, 212–217. https://doi.org/10.1109/IIAI-AAI59060.2023.00051

Priliyanti, A., Muderawan, I. W., & Maryam, S. (2021). Analisis Kesulitan Belajar Siswa Dalam Mempelajari Kimia Kelas Xi. *Jurnal Pendidikan Kimia Undiksha*, *5*(1), 11–18. https://doi.org/10.23887/jjpk.v5i1.32402

Radzitskaya, Y., & Islamov, A. (2024). Nanolearning approach in developing professional competencies of modern students: Impact on self-regulation development. *Journal of Computer Assisted Learning*, *40*(3), 1154–1165. https://doi.org/10.1111/jcal.12943

Riti, Y. U. R., Degeng, I. N. S., & Sulton, S. (2021). Pengembangan Model Pembelajaran Berbasis Proyek dengan Menerapkan Metode Design Thinking untuk Meningkatkan Keterampilan Berpikir Kritis Siswa Dalam Mata Pelajaran Kimia. *Jurnal Pendidikan: Teori, Penelitian, Dan Pengembangan*, *6*(10), 1581–1587. https://doi.org/10.17977/jptpp.v6i10.15056

Sakdiah, H., Ginting, F. W., Rejeki, N. S., & Miranda, A. (2022). STEAM Learning Against Science Process Skills Viewed from the Scientific Attitude of Students in the Vocational Physics Study Course. *Jurnal Penelitian Pendidikan IPA*, *8*(5), 2531–2536. https://doi.org/10.29303/jppipa.v8i5.2313

Seery, M. K. (2019). Research and Practice Influencing the practice of chemistry education. *Chemistry Education Research and Practice*, *20*(3), 448–451. https://doi.org/10.1039/c9rp90006c

Setianingsih, R., & Roshayanti, F. (2022). Kemampuan Berpikir Kritis Peserta Didik pada Pembelajaran Kimia dalam Pokok Bahasan Laju Reaksi di SMA Negeri 1 Bantarbolang. *Media Penelitian Pendidikan : Jurnal Penelitian Dalam Bidang Pendidikan Dan Pengajaran*, *16*(1), 5–9. https://doi.org/10.26877/mpp.v16i1.11806

Solihin, A., Wibowo, F. C., & Astra, I. M. (2021). Review of trends project based learning (PjBL) integrated STEM in physics learning. *Journal of Physics: Conference Series*, *2019*(1), 1–6. https://doi.org/10.1088/1742-6596/2019/1/012031

Sujanem, R., Suwindra, N. P., & Suswandi, I. (2022). Efektivitas e-modul fisika berbasis masalah berbantuan simulasi phet dalam ujicoba terbatas untuk meningkatkan keterampilan berpikir kritis siswa sma. *Jurnal Pendidikan Fisika Undiksha*, *12*(2), 181–191. https://doi.org/10.23887/jjpf.v12i2.54395

Sukmawati, W. (2019). Analisis level makroskopis , mikroskopis dan simbolik mahasiswa dalam memahami elektrokimia. *Jurnal Inovasi Pendidikan Ipa*, *5*(2), 195–204. https://doi.org/10.21831/jipi.v5i2.27517

Suryawan, I. P. P., Sudiarta, I. G. P., & Suharta, I. G. P. (2023). Students' Critical Thinking Skills in Solving Mathematical Problems: Systematic Literature Review. *Indonesian Journal Of Educational Research and Review*, *6*(1), 120–133. https://doi.org/10.23887/ijerr.v6i1.56462

Taqiyyah, S. A., Subali, B. S., Linuwih, S., Ellianawati, Siswanto, & Yusof, M. M. bin M. (2023). Pengembangan LKPD Berbasis Android dengan Pendekatan STEM untuk Meningkatkan Kemampuan Berpikir Kritis. *Jurnal Penelitian Pendidikan IPA*, *9*(12), 11151–11164. https://doi.org/10.29303/jppipa.v9i12.4595

Utami, T. N., Ajtmiko, A., & Suherman. (2022). Pengembangan Modul Matematika Dengan Pendekatan Science, Technology, Engineering, and Mathematics (Stem) Pada Materi segi empat. *Jurnal Pendidikan Matematika Malikussaleh*, *2*(2), 297–306.

https://doi.org/10.29103/jpmm.v2i2.9432

Vivekananth. (2022). Nanolearning: A New Paradigm Shift in Teaching and Learning. *International Journal of Engineering and Management Research*, *12*(1), 112–114. https://doi.org/10.31033/ijemr.12.1.14

Wibowo, F. C., Sanjaya, L. A., Darman, D. R., Fitri, U. R., Oktaviyanty, E., Ermawati, E. A., Nasbey, H., Mahartika, I., Widiyatmoko, A., Haeruman, L. D., & Kusuma, A. F. A. K. (2023). *Buku Nano Learning Berbasis Stem*. Yayasan Kita Menulis.

Wiratman, A., Ajiegoena, A. M., & Widiyanti, N. (2023). Pembelajaran Berbasis Keterampilan Proses Sains: Bagaimana Pengaruhnya Terhadap Keterampilan Berpikir Kritis Siswa Sekolah Dasar. *Jurnal Ilmiah Pendidikan Dasar, 08*(1), 463–472. https://doi.org/10.23969/jp.v8i1.7274

Wulandari, T. (2018). The Teaching Material Development of Problem Based Learning : Improving Student ' s Civic Knowledge. *Journal of Education and Learning (EduLearn), 12*(4), 725–730. https://doi.org/10.11591/edulearn.v12i4.9377