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Implementation of the Learning Cycle 9E with Real-Virtual Practicum to Improve Students' Critical Thinking Skills

Gani Febriani, Ika Mustika Sari*, and Iyon Suyana
Physics Education, Faculty of Mathematics and Natural Sciences Education
Universitas Pendidikan Indonesia, Bandung, Indonesia
*ikams@upi.edu

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Abstract

Rapid advancements in science and technology have made critical thinking skills increasingly essential. 21st-century education focuses not only on knowledge transfer but also on developing crucial skills to meet future challenges. This study examines the enhancement of students' critical thinking skills by implementing the Learning cycle of the 9E model, which integrates real and virtual practicums on dynamic fluid materials. The research used a pre-experimental design with a pretest-posttest approach involving 27 grade XI students selected via purposive sampling. Data were collected using a critical thinking skills test with 19 two-level multiple-choice questions and analyzed with Rasch modeling techniques. Results showed that the Learning cycle of the 9E model, combining real and virtual practicums, improved students' critical thinking skills by 5.74 logits, indicating a medium level of improvement. The racking technique revealed that initially, difficult questions became easier post-intervention, highlighting a positive impact on learning. Thus, the Learning cycle of the 9E model with real-virtual practicums effectively enhances students' critical thinking skills in dynamic fluid materials. These findings have significant theoretical and practical implications, supporting classroom learning and educational policies. The stacking and racking techniques provide deeper and more accurate analysis results.

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INTRODUCTION

Society must adapt to these changes as science and technology advance, including education. The education system must be updated to remain relevant to current needs, focusing on developing individual mindsets and character (Boncquet et al., 2024; Lukum et al., 2024). 21st-century education aims to develop quality students who can compete globally by enhancing skills known as the 6Cs: Character, Citizenship, Critical Thinking, Creativity, Collaboration, and Communication (Anggraeni et al., 2022; Anugerahwati, 2019). Critical thinking is one of the important skills to face the challenges of the 21st century (Susilawati et al., 2020; Yuniarti et al., 2019). According to Ennis in Agnafia (2019), critical thinking is thinking rationally, focusing on beliefs and decisions. These skills include information analysis, in-depth argument evaluation, knowledge integration, and evidence-based assessment. Critical thinking skills can be developed through learning

methods such as discussion, expressing opinions, and practical activities (Saputra et al., 2019). The Independent Curriculum emphasizes the importance of critical and scientific thinking skills (Kemdikbud, 2017). Therefore, these skills need to be honed through education, including physics learning.

Physics serves as a medium for teaching critical thinking skills through a scientific approach (Mitrevski, 2019; Wenno et al., 2022; Yanti et al., 2020) Learning physics contributes to enhancing the nation's quality by developing students' abilities to think scientifically, rationally, and critically, as well as understanding concepts and solving everyday problems (Siswadi et al., 2018). Therefore, critical thinking skills must be cultivated in education and be key to building students' knowledge to face 21st-century challenges.

A preliminary study at a state high school in Bandung, using diagnostic tests and interview methods, revealed that students' critical thinking skills were low. This is evidenced by students' difficulty answering questions and understanding basic physics concepts. The primary cause is that traditional teaching methods focus on teachers and lack practical experience. Consequently, classroom activities often do not engage students directly, with only one or two students daring to ask questions and provide answers. The lack of practice in critical thinking skills results in students struggling to solve problems and apply their knowledge daily. This aligns with research by Hasriani et al. (2020), which shows that the percentage of students' critical thinking is very low, ranging from $0 < x \leq 43.75\%$. Students also appear passive in group discussions and assignments, indicating low participation and initiative (Basri et al., 2019; Hadisaputra, 2020). The frequent use of memorization learning methods causes students to forget the information they receive quickly. Therefore, changes are needed in the learning process by creating models and media that support student's active participation, understanding of concepts, and development of critical thinking (Fadilah et al., 2024; Hadisaputra et al., 2020).

One alternative learning model that can be applied is the Learning cycle of 9E, which comprises nine phases: elicitation, engagement, exploration, explanation, echo, elaboration, evaluation, emendation, and e-search (Sadraei et al., 2022). This model is an extension of the Learning Cycle 3E, 5E, and 7E, prioritizing constructivism, focusing on active student involvement, and allowing them to interact, gather, and reflect on data to develop their theories (Kartini et al., 2021). This model can sharpen students' creative and critical thinking skills (Kaur & Gakhar, 2015). Research by Saad et al. (2023) and Anggun (2024) supports that the Learning cycle of the 9E model can enhance students' critical thinking skills. According to Junilita et al. (2022), the Learning cycle of the 9E model is very supportive and adaptable when integrated with ICT-based learning media. One of the rapidly developing media is the virtual laboratory, which can address the lack of practical sessions due to limited facilities. Research by Lestari and Supahar (2020) indicates that 94.3% of students need this medium to support practical sessions. Supahar and Widodo (2020) proposed a laboratory model with a virtual instrument system (Lab-Vis) to optimize real laboratories. Virtual laboratories can be an alternative, especially in schools with limited practical tools and materials (Oser & Fraser, 2015). The benefits of virtual laboratories can offer solutions to various school problems. PhET simulations are an effective example, aiding students in understanding materials by independently collecting data (Haryadi & Pujiastuti, 2020; Patrascoiu, 2017). Research by Amala et al. (2020) demonstrated the effectiveness of PhET in physics learning, making it more engaging and increasing students' active participation and critical thinking skills (Ngadinem, 2019; Verdian et al., 2021).

Although virtual practicums offer many opportunities for students to explore, direct interaction with real objects remains essential (Lestari & Supahar, 2020). Research by Toth et al. (2014) indicates that combining virtual labs with hands-on laboratories can enhance students' conceptual knowledge and critical thinking skills. Dynamic fluids, a physics topic

studying the movement of fluids, are important in everyday life, including water, air, and blood flow. Lin and Miao (2022) stated that dynamic fluids play a crucial role in astronomy, meteorology, oceanography, and engineering and are used in wind tunnel testing, dam design, and aerodynamic structures. A deep understanding of dynamic fluids opens career opportunities as engineers and technicians. However, a Physics teacher at MAN 11 Jakarta noted that grade XI students often struggle to understand this material, as evidenced by low learning outcomes and the need for remedial classes after end-of-semester exams. Research by Nurjanah et al. (2022) shows that students' critical thinking skills on this topic are still low, with an average score of 52.3 out of 100. Patricia (2018) found that 89.28% of students had difficulty learning dynamic fluids due to a lack of understanding, inability to formulate problems, and difficulty inferring and associating materials. These challenges are caused by a lack of learning experience and student engagement (Shidqi & Anggaryani, 2020).

Based on the description above, the novelty of this study is the innovation provided by the 9E learning cycle with a combination of real-virtual practicum. This method integrates direct practicum at the exploration stage and virtual laboratories at the e-search stage. This approach aims to improve students' conceptual knowledge and critical thinking skills that were not explored in previous research. Therefore, this study aims to analyze the improvement of students' critical thinking skills after applying the Learning cycle of the 9E learning model with a combination of real-virtual practicum on dynamic fluid materials.

METHODS

This study uses a quantitative method with a pre-experimental design and a one-group pretest-posttest design without using a control class. The population of this study is all grade XI students, with purposive sampling techniques. The research sample is class XI-4, consisting of 27 students. The data collection technique used is a test to measure students' critical thinking skills. The test instrument consists of 19 pre-test and post-test questions in two-tier multiple. Two-tier multiple choice is used because it effectively measures high-level thinking skills, including critical thinking skills, and can reduce measurement errors compared to conventional multiple-choice. Each question has two components: the first tier is multiple-choice, and the second tier is the choice of reason against the first tier. The test questions refer to the indicators of critical thinking skills, according to Ennis (1985), namely elementary clarification, basic support, inference, advanced clarification, and strategy and tactics. The question instrument has been validated by five experts and tested on 57 students, showing validity and reliability with a Cronbach Alpha score of 0.70.

Improving students' critical thinking skills was measured using Rasch modeling with stacking and racking techniques for individual analysis. Rasch modeling is used to analyze the feasibility of instrument items, identify incorrect answers and assessments, and predict missing data based on systematic response patterns. Previous research has demonstrated that the Rasch model effectively analyzes the quality of instrument items and students' abilities. This study measured critical thinking skills through pre-tests and post-tests, with the results converted to the same interval scale, turning ordinal data into ratios. The logarithmic function generates log odds units, showing the relationship between students' abilities and the difficulty level of question items (Sumintono, 2016).

Stacking analysis was used to compare students' abilities before and after the intervention, while tracking analysis compared the difficulty levels of the questions before and after the intervention, with the data converted into equal interval scales.

The improvement in students' critical thinking skills as measured by the logit value and location change on the vertical ruler, as displayed in Ministep software version 5.8.0 (Laliyo et al., 2022). This technique allows individual and comprehensive identification of changes in students' abilities due to the intervention, providing precise and accurate measurements (Sukarelawan et al., 2024).

RESULTS AND DISCUSSION

The enhancement of critical thinking skills was assessed using pre-test and post-test results with Rasch modeling and stacking and racking techniques. The test comprises 19 questions covering five aspects of critical thinking skills, according to Ennis (1985), with scores ranging from 0 to 3. These scores were analyzed to describe the improvement in students' skills following implementing the learning cycle 9E model combined with real-virtual practicums. The stacking technique compares critical thinking skills through logit values before and after the intervention. A positive increase indicates an enhancement in ability, while a negative value signifies a decline (Laliyo et al., 2022)To facilitate tabulation, Participants were assigned codes based on sequence number and gender. Table 1 presents the results of the pre-test and post-test analysis.

Table 1 Measures of critical thinking skills improvement

Learners	Pre-test	Post-test	Improved logit	Information
01L	0.91	2.21	1.30	Positive
02P	-2.00	4.18	6.18	Positive
03L	-1.11	4.24	5.35	Positive
04P	-4.22	4.45	8.67	Positive
05L	-2.24	4.35	6.59	Positive
06P	-0.56	4.44	5.00	Positive
07L	-2.66	4.46	7.12	Positive
08L	1.03	2.32	1.29	Positive
09L	-2.93	4.46	7.39	Positive
10L	-2.42	2.12	4.54	Positive
11P	-4.46	4.46	8.92	Positive
12P	-4.21	4.46	8.67	positive
13P	-4.32	3.14	7.46	Positive
14L	-0.62	4.33	4.95	Positive
15L	0.22	4.33	4.11	Positive
16L	-3.61	4.19	7.8	Positive
17L	-2.97	-2.55	0.42	Positive
18L	-4.04	4.19	8.23	Positive
19L	-2.86	4.33	7.19	Positive
20L	0.05	4.33	4.28	Positive
21L	-1.53	4.14	5.67	Positive
22L	-0.76	4.46	5.22	Positive
23P	-4.34	3.07	7.41	Positive
24L	-0.83	4.46	5.29	Positive
25P	-1.79	4.46	6.25	Positive
26P	-1.31	4.33	5.64	Positive
27P	0.13	4.24	4.11	Positive

Learners	Pre-test	Post-test	Improved logit	Information
Average	**-1.98**	**3.76**	**5.74**	**Positive**

Based on Table 1, it is evident that 100% of students have shown improvement in critical thinking skills. The average critical thinking skills score in the pre-test was -1.98 on the logit scale. After using the Learning cycle of the 9E model combined with the real-virtual practicum, the average score increased by 5.74 logits, from -1.98 to 3.76 logits. This shows a significant improvement in students' critical thinking skills. This improvement shows that the Learning cycle of the 9E model, when combined with real-virtual practicum, positively impacts students' critical thinking skills. These findings support previous research by Anggun (2024), which shows that the Learning cycle of the 9E model can improve critical thinking skills. In addition, using virtual laboratories, such as PhET simulations, and hands-on practicum has also been shown to improve critical thinking skills, according to research by Toth et al. (2014). The comparison of students' critical thinking skills during the pre-test and post-test is illustrated in Figure 1. The graph in Figure 1 compares students' critical thinking skills at the time of the pre-test and post-test.

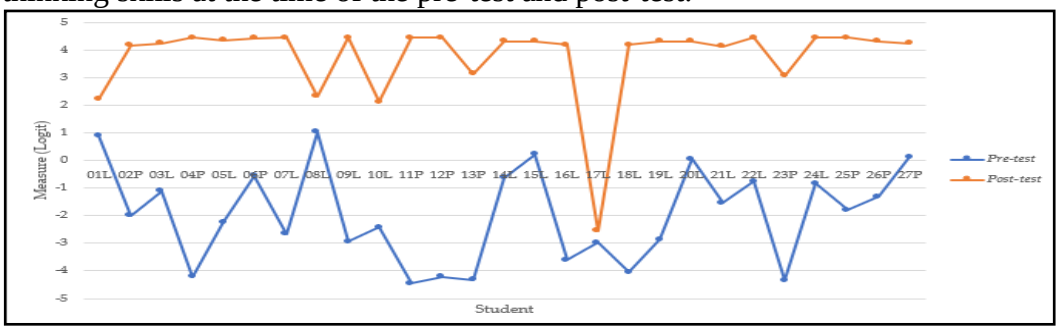

Figure 1 Comparison chart of pre-test and post-test CTS levels

Based on the graph above, significant variation in critical thinking skills among students was found. Prior to the implementation of the learning cycle o9E learning with a combination of real-virtual practicum, at the time of the pre-test, 11P students had the lowest level of critical thinking skills, while 08L students had the highest level of critical thinking skills. After implementing the Learning cycle of 9E learning with a combination of real-virtual practicum, there was a significant increase in critical thinking skills. The highest increase in critical thinking skills occurred in 11P students, who increased by 4.46 logits, from -4.46 logits to 4.46 logits, and the lowest improvement in critical thinking skills occurred in 17P students, who experienced an increase of 0.42 logits, from -2.97 logits to -2.55 logits.

Figure 2 illustrates the level of critical thinking skills of students at the time of pre-test and post-test. The right part of the map shows the learners' ability level. The "pre" code refers to the pre-test, while the "post" code refers to the post-test. For example, "01Pre" indicates the number 1 learner who took the pre-test. Learners' abilities are distributed from -3 to +4 logit scales. The bottom right part of the map shows students with a low level of critical thinking skills, while the top right part shows students with a high level of critical thinking skills. The higher the position on the map, the higher the level of critical thinking skills. The left side of the map depicts the distribution of items. Items with a high difficulty level are placed at the top left, while items with a low difficulty level are placed at the bottom left.

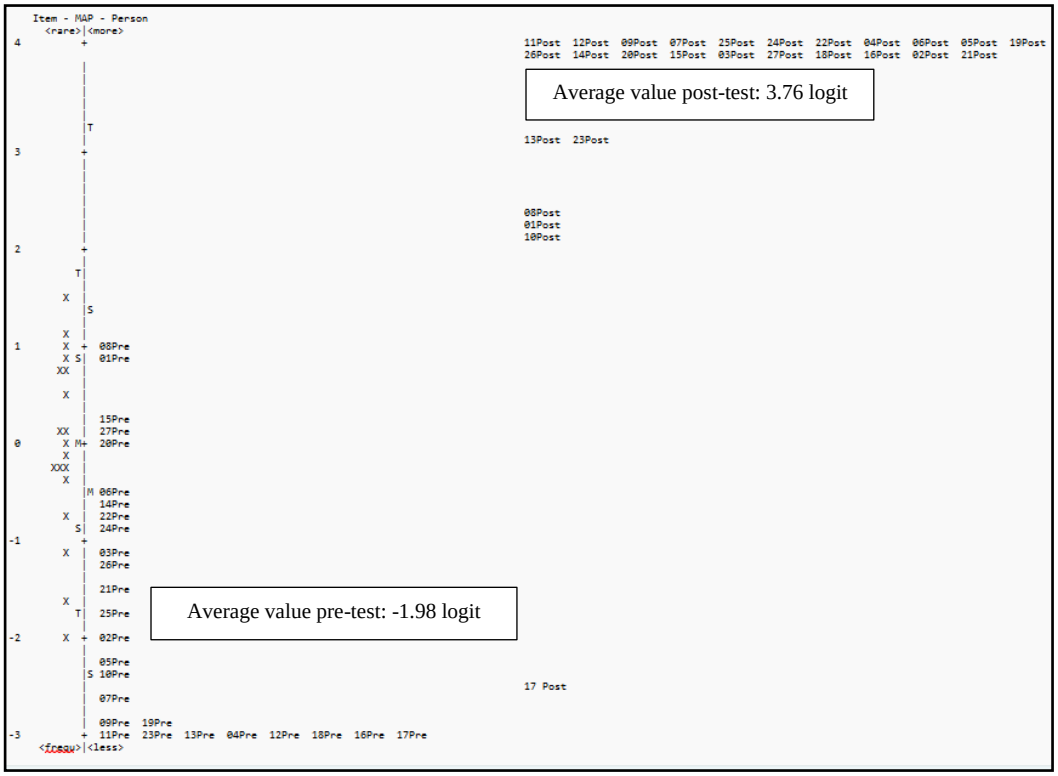

Figure 2 Variable (wright) maps CTS improvement

Based on Figure 2, we can see the condition of the student's ability, which is associated with the item's difficulty level. Questions below the student's location have a more than 50% chance of being answered correctly, while questions above the student's location have a less than 50% chance of being answered correctly. For example, students 04, 05, 07, 09, 10, 11, 12, 13, 16, 18, 19, and 23 had the lowest level of critical thinking skills in the pre-test and could not solve a single question. After the intervention, their skills improved, and they could answer all 19 questions correctly. Another interesting example is participant number 17, whose critical thinking skills did not improve either before or after the intervention, showing consistency in his level of critical thinking skills. This is in line with research conducted by Ariani (2020), which states that students' critical thinking skills do not improve due to a lack of in-depth understanding of basic physics concepts.

The criteria for grouping students' critical thinking skills are based on the average logit score and standard deviation. Standard deviation is used to identify groups of learners (Sumintono & Widhiarso, 2015). In this study, the standard deviation was 2.23, and the average was 5.74 on the logit scale. The grouping criteria for improving students' critical thinking skills are presented in Table 2.

Table 2 Criteria for grouping CTS improvement

Logit Value	Criterion
> logit 12.43	Top Outlier
7.97 < logit ≤ 10.20	Very High
5.74 < logit ≤ 7.97	High
3.51 < logit ≤ 5.74	Medium
1.28 < logit ≤ 3.51	Low
logit < 1.28	Lower Outlier

Based on the criteria for grouping critical thinking skills, logit scores that meet the lower outlier criteria indicate students with very low critical thinking skills, while logit scores that meet the upper outlier criteria show students with very high critical thinking skills (Sumintono & Widhiarso, 2015). The following is a diagram of the results of grouping the improvement of students' critical thinking skills after implementing the Learning cycle of 9E learning with a combination of real-virtual practicum.

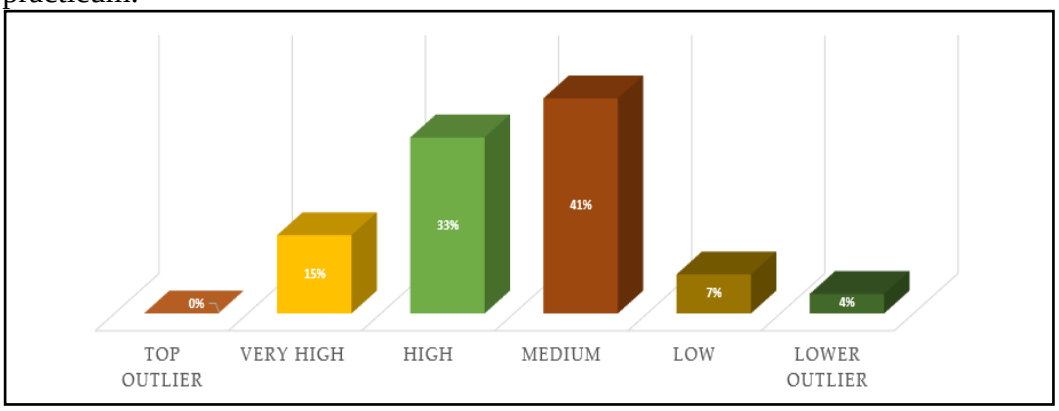

Figure 3 Number of distribution of criteria for increasing student CTS

Based on Figure 3, the learning cycle of the 9E class with a combination of real-virtual practicum has succeeded in improving students' critical thinking skills. As many as 41% of students (18 people) are in the medium category. The high category covers 33% of students (9 people), while the high category covers 15% (4 people). The low category includes 7% of students (2 people) and 4% (1 person) in the lower outlier category. Thus, data analysis pretest-posttest Using the stacking Rasch model shows that the learning model Learning cycle of 9E with a combination of real-virtual practicum can improve students' critical thinking skills in the medium category. The overall analysis showed an improvement in the critical thinking skills of all students. This indicates that the learning model learning cycle of the 9E class with a combination of real-virtual practicum positively impacts students' critical thinking skills on dynamic fluid materials.

Analysis racking It is used to detect changes in the difficulty level of question items in the Critical Thinking Skills Test based on logical scores. A high logit score indicates a difficult question, while a low logit score indicates an easy question item. Positive changes indicate that problems that were initially easy become difficult, while positive changes occur that decrease in logical values indicate that problems that were originally difficult become easy (Laliyo, 2021). Patterns of changes in the difficulty level of questions between pre-test and post-test can be seen in Table 3.

Table 3 Changes in the difficulty level of CTS questions

No Item	Logit item Pre-test	Logit item Post-test	Item logit difference	Information
1	1.85	-2.58	-4.43	Negative
2	0.54	-5.04	-5.58	Negative
3	1.68	-5.08	-6.76	Negative
4	2.10	-2.93	-5.03	Negative
5	1.55	-2.53	-4.08	Negative

No Item	Logit item Pre-test	Logit item Post-test	Item logit difference	Information
6	2.62	-4.47	-7.09	Negative
7	1.46	-4.43	-5.89	Negative
8	3.02	-2.48	-5.50	Negative
9	0.95	-4.63	-5.58	Negative
10	3.70	-4.61	-8.31	Negative
11	2.12	-5.08	-7.20	Negative
12	3.47	-7.44	-10.91	Negative
13	2.61	-5.00	-7.61	Negative
14	4.09	-3.32	-7.41	Negative
15	3.48	-5.08	-8.56	Negative
16	3.63	-3.63	-7.26	Negative
17	2.67	-3.32	-5.99	Negative
18	2.20	-4.63	-6.83	Negative
19	2.77	-3.09	-5.86	Negative
Average	**2.45**	**-4.18**	**-6.84**	**Negative**

Table 3 shows the average difficulty level of the pre-test questions is 2.45 on the logit scale. After implementing the Learning cycle of 9E learning with a combination of real-virtual practicum, there was a decrease in the average logit score of -6.84, from 2.45 to -4.18 on the logit scale. This decrease shows that the Learning cycle of 9E learning with a combination of real-virtual practicum significantly improves students' critical thinking skills so that previously difficult problems for students become easy. The difference between the pre-test and post-test logit scores on nineteen items was more than -0.5, indicating a significant decrease.

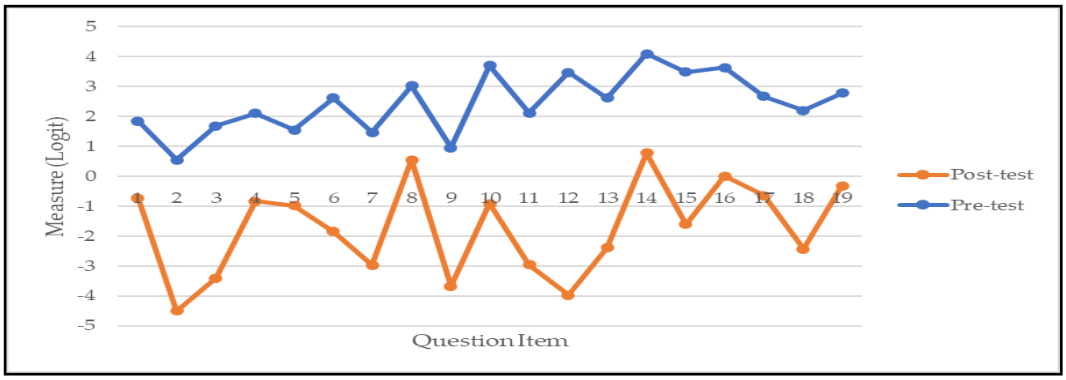

Figure 4 Comparison chart of CTS item difficulty

Based on Figure 4, all question items experienced significant changes in difficulty. Questions 1-5 measure elementary clarification critical thinking skills; questions 6-8 measure basic support; questions 9-13 measure inference; questions 14-16 measure advanced clarification; and questions 17-19 measure strategy and tactics. Changes in the category of each question item can be seen in Table 4. The classification of question items in this study is based on the analysis of the standard deviation value, which is 3.53.

Table 4 Category changes in difficulty of CTS items

Pre-test			Post-test		
Question Items	Logit	Category	Question Items	Logit	Category
1	1.85	Difficult	1	-2.58	Easy
2	0.54	Difficult	2	-5.04	Very easy
3	1.68	Difficult	3	-5.08	Very easy
4	2.10	Difficult	4	-2.93	Easy
5	1.55	Difficult	5	-2.53	Easy
6	2.62	Difficult	6	-4.47	Very easy
7	1.46	Difficult	7	-4.43	Very easy
8	3.02	Difficult	8	-2.48	Very easy
9	0.95	Difficult	9	-4.63	Very easy
10	3.70	Very difficult	10	-4.61	Very easy
11	2.12	Difficult	11	-5.08	Very easy
12	3.47	Difficult	12	-7.44	Very easy
13	2.61	Very difficult	13	-5.00	Very easy
15	4.09	Very difficult	15	-3.32	Easy
16	3.48	Difficult	16	-5.08	Very easy
17	3.63	Very difficult	17	-3.63	Very easy
18	2.67	Very difficult	18	-3.32	Easy
19	2.20	Difficult	19	-4.63	Very easy

Table 4 shows that all question items in the CTS instrument have changed in difficulty, from initially difficult or very difficult to easy or very easy. Thus, the analysis of pretest-posttest data using the Racking Rasch model technique shows that learning the Learning cycle of the 9E model with a combination of real-virtual practicum can improve students' critical thinking skills, where problems that were originally difficult and very difficult turn into easy and very easy. The comparison chart of the level of critical thinking skills indicators at the time of the pre-test and post-test is seen in Figure 5 as follows.

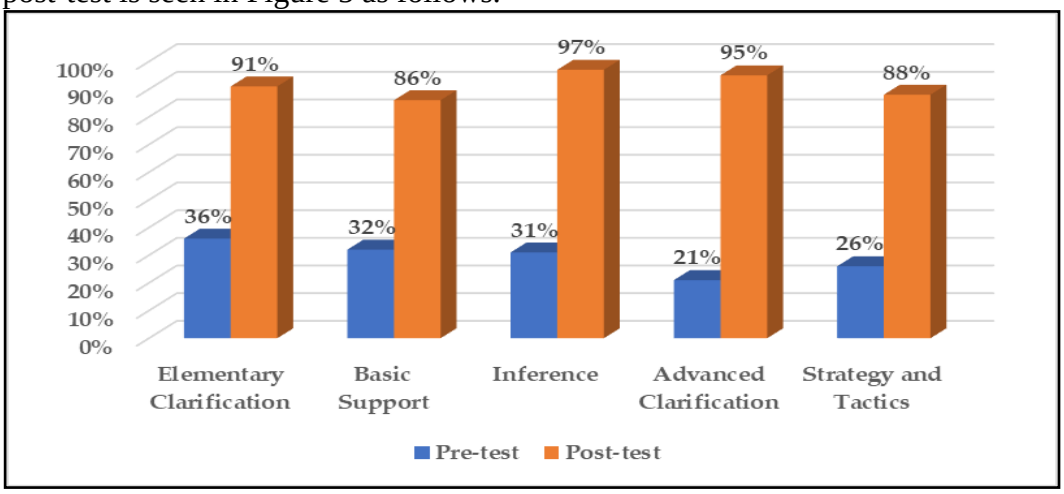

Figure 5 Comparison of CTS pre-test and post-test indicator levels

Based on Figure 5, significant improvements were seen in all indicators after the intervention, indicating that students were more capable in various aspects of critical thinking skills. In elementary clarification, the increase from 36% to 91%

showed a better ability to explain basic concepts. Basic support went from 32% to 86%, indicating increased skills in supporting their arguments. Inference experienced the largest jump from 31% to 97%, indicating that students are more proficient in drawing logical conclusions. Advanced clarification increased from 21% to 95%, indicating deeper understanding and higher analytical capabilities. Finally, strategy and tactics increased from 26% to 88%, significantly improving planning and implementing strategies. Overall, the data showed a significant improvement in students' critical thinking skills in all categories after the intervention. Substantial improvements were particularly noticeable in the subsequent inferences and clarifications, confirming that the training honed various aspects of students' critical thinking skills. This is in line with Anggun's (2024) research, which states that the 9E learning cycle model improves students' critical thinking skills.

The learning cycle 9E model consists of nine phases: elicitation, engagement, exploration, explanation, echo, elaboration, evaluation, emendation, and e-search (Buwono et al., 2020). The process begins with an elicitation to draw students' attention to the previous material, followed by engagement that actively engages students. Exploration encourages students to explore through direct practicum, while in explanations, they present the results of their findings. Echo reinforces the material already studied, and elaboration expands understanding through new cases. Evaluation includes working on questions, while emendation focuses on improving the learning process. The final phase, e-search, integrates technology with virtual practicums to verify data from live practicums and deepen the concepts learned to improve students' understanding.

The 9E learning cycle model transforms students from passive listeners to active participants in the learning process (Tanfiziyah et al., 2021). In addition, the learning cycle 9E improves students' competencies and skills (Kaur & Gakhar, 2015). Students are encouraged to ask questions, collect, record, and reflect on data, form their theories, and hone creative, critical, and self-control thinking skills (Kartini et al., 2021).

The learning cycle 9E emphasizes student activities in exploring materials, building knowledge, and applying the concepts learned. This allows for a meaningful and constructive learning experience. Recent research by Anggun (2024) shows that this model improves students' critical thinking skills. Saad et al. (2023) also stated that this model effectively develops critical analysis and inference skills.

In addition to hands-on practice that strengthens understanding (Toth et al., 2014), appropriate learning media is also important. Junilita et al. (2022) stated that the learning cycle 9E model adapts well to ICT-based media, including virtual laboratories. The learning cycle 9E model applies the use of virtual laboratories to the last syntax, which is the e-search stage. At this stage, virtual practicum is used to verify the data obtained so students understand the material correctly. However, virtual labs are more effective adjunct than a substitute for hands-on practice (Burkett & Smith, 2016).

Research by Kapici et al. (2019) shows that the use of hands-on practice along with virtual laboratories is more effective in increasing student knowledge than using only one practicum method. Other advantages of virtual laboratories include time savings (De Jong et al., 2013) and the use of elements such as animation, video,

and images that can increase student interest and participation (Alneyadi, 2019). In addition, virtual laboratories can also improve students' ability to understand the material, think critically, and hone their ICT skills (Yanti et al., 2019). However, virtual laboratories can reduce direct interaction between students and teachers due to the largely electronic communication and limited use of simulations (Clarinda et al., 2022). Therefore, virtual laboratories should be used as support, not replace conventional laboratories with minimal equipment in schools.

CONCLUSION

When combined with real-virtual practicums, the Learning cycle of the 9E model has been shown to effectively enhance students' critical thinking skills. This research, however, is limited to a single class with a small sample size. Consequently, it is recommended that future studies include two classes for comparison and a larger sample size to yield more comprehensive and representative results. This research has significant theoretical and practical implications. The Learning cycle of the 9E model not only effectively improves critical thinking skills and can be applied to various other subjects. Education policymakers might consider integrating this model into the curriculum. The stacking and racking methods in Rasch modeling analysis provide more detailed and accurate findings.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

The authors contributed as follows: GF was responsible for conducting the experiments, data analysis, and drafting the initial manuscript. IMS and IS contributed to the conceptualization and methodology.

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AUTHOR PROFILES

Gani Febriani is a S1 student of the Physics Education Study Program at the University of Education Indonesia. He has expertise in scientific writing and the field of physics, as evidenced by the publication of a journal on Sinta 5. In addition, Gani has taught the National Science Olympiad (OSN) for elementary and high school students, demonstrating his dedication in guiding the younger generation in physical science. Gani can be reached via email at ganifbr@upi.edu.

Dr. Ika Mustika Sari, S.Pd., M.PFis., is a lecturer at the Physics Education Study Program FPMIPA UPI who has expertise in scientific research and publications in the field of Physics Education. He can be reached via email at ikams@upi.edu. Dr. Ika Mustika Sari has profiles on several academic platforms, namely Google Scholar, Sinta, ORCID, and Scopus. His work history includes experience as a lecturer at several institutions as well as positions in decentralized education projects funded by USAID. In addition, he has experience teaching various courses such as Basic Physics, Basic Physics Experiments, and Mechanics. He is also active in various researches that focus on improving students' data literacy and scientific argumentation skills.

Drs. Iyon Suyana, M.Si., is a lecturer at the University of Education Indonesia (UPI) with a strong educational background and extensive experience in the field of physics education. Born on August 24, 1962, Drs. Iyon Suyana studied S1 at IKIP Bandung and earned a S2 degree at the University of Indonesia. Currently, he teaches various courses at UPI, including Experiments in Fundamental Physics and Quantum Physics. In addition, Drs. Iyon Suyana is active in various training and training activities, and is often a presenter in scientific seminars in various regions. He also has numerous publications in various scientific databases such as Sinta, Scopus, and Google Scholar, which include research on student misconceptions in physics and the use of computer simulations in physics learning. You can contact him via email at iyons@upi.edu. His contributions to scientific research and publications show his dedication to developing physics education in Indonesia.