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Improving Critical Thinking Skills Through Higher Order Thinking Skills (HOTS)-Based Science

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Through various strategies and learning models, efforts have been made to improve students' critical thinking skills in elementary and secondary school science classrooms. However, there are still a few research results that show efforts to improve critical thinking skills through Higher Other Thinking Skill (HOTS)-based science questions. Therefore, this study aims to test the effectiveness of students' habituation to HOTS-based science questions in improving students' critical thinking skills in science. In this study, students who were exposed to the HOTS-based science questions and who were not are being compared. The method used is an experimental method with a Pretest Posttest Non-Equivalent Control Group Design. This study involved 165 students from one of the Public Junior High Schools in Banda Aceh, Indonesia. To collect data related to critical thinking skills, a pretest, and posttest were administered, where each test used a long answer HOTS-based science questions. The data obtained from the test were then analyzed using descriptive and inferential statistical techniques. This study found that the habituation of HOTS-based science questions can effectively improve students' critical thinking, indicated by a significant difference in critical thinking skills scores in science between the control (n=81) and the experimental classes (n=84). The results of this study are expected to provide an overview and benefits for practitioners of science education to improve critical thinking skills in science using HOTS questions.

Keywords: HOTS, critical thinking, habituation, science questions, Cohen's Kappa, semantic differential scale

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INTRODUCTION

Indonesia is one of the member countries participating in the Programme for International Student Assessment (PISA). Based on the latest PISA report released in 2018 showed that the literacy level of Indonesian students ranked 74th out of 79 member countries (OCED, 2018). It should certainly be a concern for Indonesia because the literacy level of a country will have a strong impact on the competitiveness of its people in the era of global competition (Fitriansyah et al., 2020; Nair et al., 2012). The level of scientific literacy greatly determines the competitiveness of a nation (Amaringga et al., 2021) because scientific literacy is a skill in using individual scientific knowledge to solve problems (Feinstein, 2011; Zulfiani et al., 2020). Along with global technological development, scientific literacy is a crucial aspect that the next generation of Indonesia must master. Despite the importance of the scientific literacy of a nation in global competition, the level of scientific literacy of students in Indonesia is lacking. In the 2018 PISA report, Indonesia ranked 74th, lagging behind other ASEAN countries. This, of course, must be a special concern for all components of the country, especially in the field of education, so that the quality of science learning in Indonesia can be improved. One of the efforts that can be made is innovation in the learning process by improving students' critical thinking skills in science. According to Garbacz (2023), science literacy refers to the scientific knowledge that should be posed to make a decision based on facts, research, and knowledge or not based on myth or opinion. By applying critical thinking and questioning, students are expected to have skills in decision-making that fulfill the skill of scientific literacy.

Critical thinking is the skill to think about objects, contents, or problems thought by the thinker in improving the quality of his thinking by skillfully taking the structural content inherent in thinking and imposing intellectual standards on them (Cottrell, 2017). According to Ennis (2011), critical thinking is thinking logically and reflectively and deciding what to do. From these opinions, it can be concluded that critical thinking is a skill practiced by utilizing various objects and concepts to solve a problem. Critical thinking skill is a tool for solving contextual problems and non-contextual problems (Thayer-Bacon, 1998). A survey conducted by the Association of American Colleges and Universities (American Management Association, 2019) showed that 75% of employers wanted colleges to place more emphasis on critical thinking, real-world problem-solving, communication, and creativity, and 93% of these employers felt that these skills were more important than others. According to Phillips et al. (2004), to find out whether someone has critical thinking skills, five aspects can be assessed, namely: analytical skill, inferring skill, evaluating skill, inducting skill, and deducting skill. Details of each aspect of critical thinking skills are presented in Table 1. Efforts to improve critical thinking skills in the field of science can be pursued through the habituation of students by asking and answering questions in the field of science with questions based on Higher Order Thinking Skills (HOTS). In addition, Bogdanovich (2014) explained that higher order problems expect students to answer questions by applying, analyzing, synthesizing, and evaluating information rather than recalling facts to promote critical thinking skills. HOTS is a skill to do something about facts, understand them, conclude them, relate them to new facts, and apply them to find solutions to problems (Table 1) (Thomas & Thorne, 2009).

Table 1
Aspects of critical thinking

Aspect	Description
Analysis	The skill is identifying a situation's elements and determining how the parts interact.
Inference	The skill to sum up the reasons and evidence available.
Evaluation	The skill to assess the credibility of sources of information and claims made.
Induction	The skill to decide in a context of uncertainty relies on inductive reasoning.
Deduction	The skill to make the right decision where all the conditions determine the outcome depending on strong and deductive reasoning skills

In Bloom's Taxonomy, HOTS requires mastery of thinking and skills at analyzing, evaluating, and creating (Anderson & Krathwohl, 2001). Critical thinking skills are necessary to fulfil skills at analyzing, evaluating, and creating (Misrom et al., 2020; Purnami et al., 2021). Therefore, to improve students' critical thinking skills in science, it is necessary to practice solving Higher Order Thinking Skills (HOTS) questions in science. The habituation of solving HOTS questions in science must be carried out in learning by considering the importance of critical thinking skills.

Many studies have been conducted in order to improve student's critical thinking skills (Elder & Paul, 2010; Forawi, 2016; Ishartono et al., 2021a; Ishartono et al., 2021b; Misrom et al., 2020; Permana & Utomo, 2021; Stephenson & Sadler-Mcknight, 2016; Vierra & Tenreiro-Vieira, 2016). These studies revealed critical thinking skills and the development of HOTS-based questions at the elementary school level. However, research on improving the critical thinking skills of junior high school (SMP) students through solving Higher Order Thinking Skills (HOTS) problems in science is limited. Therefore, it needs to be studied more deeply because improving critical thinking skills can help students prepare to face global competition through aspects of science. The research question is whether the practice of working on Higher Order Thinking Skills (HOTS) questions in science is effective in improving the critical thinking skills of junior high school students. Therefore, this study aims to test the effectiveness of the exercise on Higher Order Thinking Skills (HOTS) questions in science in improving students' critical thinking skills. This research hypothesizes that the practice of solving Higher Order Thinking Skills (HOTS) questions in science can improve the critical thinking skills of junior high school students.

METHOD

The research method used is experimental with (Gall et al., 2003) Pretest Posttest Non-Equivalent Control Group Design (Table 2). The treatment group is the class that is given the practice of solving HOTS questions. This is based on the statement given by Hannel and Hannel (1998) that one step of critical thinking is to perform an analysis that is also accommodated by the HOTS type of problems so that the relationship between the HOTS science questions with critical thinking skills is the requirement of analysis step in solving problems in science. The control class is taught using a lecturing method where the teacher only carries out the learning process by explaining the material directly to students (Benjamin Jr., 2013).

Table 2
Pretest posttest non-equivant control group design

Sample	Class	Pretest	Treatment	Posttest
Not Random	A (Treatment)	O	O	O
Not Random	B (Control)	O	X	O

Description:
O: Given Treatment
X: Not Given Treatment

Table 2 explains that the sign O means the action is carried out, while the X means that the action is not carried out. The first step in this study was to conduct an initial ability test through pretest activities in both the treatment and control classes to determine students' initial critical thinking skills. Posttest was conducted to obtain data about students' final level of critical thinking skills after the treatment. Posttests were also carried out in both classes, namely the treatment and control classes.

Critical thinking ability data were obtained based on the pretest and posttest results. The assessment was based on the assessment rubric based on critical thinking aspects, namely analytical skill, inference skill, evaluation skill, induction skill, and deduction skill (Table 1). The assessment score was based on the semantic differential scale with categories 1 "very low", 2 "low", 3 "moderate,", 4 "high," and 5 "very high" (Gliner et al., 2016). Finding out whether there was an increase in critical thinking skills and testing the hypothesis was done by comparing the pretest score with the posttest score of students' critical thinking skills between the treatment class and the control class through statistical analysis of Covariance Analysis (ANCOVA). ANCOVA test was used for a quasi-experimental study with no random groups sample, and the groups are statistically equal on one or more variables which may differ across groups (Newsom, 2023). ANCOVA statistical analysis was conducted using SPSS software (Ruseffendi, 2018; Santoso, 2017). In addition, descriptive analysis was also carried out by describing the data obtained in depth. Therefore, to see the differences between each critical skill aspect in posttest results between both classes, the Analysis of Variance (ANOVA) test was conducted. At this point, the test is used to see whether the students between the control and experiments group have different abilities in each critical skill aspect (analytical, inferential, evaluating, induction, and deduction).

This research was conducted in six Grade 8 classes in one of the Public Junior High Schools in Banda Aceh, Indonesia. The sampling was selected by total sampling technique, where all six parallel classes were used as research samples. Three were designated treatment classes, and the other three were control classes. The determination of the treatment class and control class was carried out non-randomly (Table 2). The number of students involved in this study was 165, with details of 84 students in the treatment class and 81 in the control class.

Based on the research objectives, the data collection technique in this study was through tests (pretest and posttest). These tests were conducted using questions about the eighth-grade junior high school science material based on HOTS. The test includes several biology topics: organism structure, physiology, and genetics. The questions were designed in the form of 25 problem-based essay questions. The test was validated by two experts in science from the Department of Biology Education, Universitas Syiah Kuala. In addition, these questions were also tested for reliability using ANATES V4 software (Ariany & Al-Ghifari, 2018), and it was found that the reliability value was 0.64 (adequate) (Bendig, 1954).

Before giving the solutions to the HOTS-based science questions, the researchers previously provided training for teachers in developing HOTS-based science questions suitable for junior high school students for three days. After that, the researchers and the teachers conducted a focus group discussion (FGD) which discussed the implementation of HOTS-based science questions to students. After completing the training and FGD, the teacher administered the students the HOTS-based science questions.

The pretest was given during the class meeting. This study had eight lessons (2 lessons each week). The teacher administered the pretest questions in the partition. Two to three pretest questions were given before the class began. Thus, the posttest was given in one time with 25 questions after all the class meetings were completed.

FINDINGS

The measurement of student's critical thinking skills (Figure 1) shows that the average pretest score between the experimental and control classes is the same (1.91). Meanwhile, the posttest score of the experimental class shows a higher score (M=4.03) than the control class (M=2.13). The difference between the pretest and posttest scores shows that the experimental class scores higher (M=2.12) than the control class (M=0.22). These data indicate a higher increase in critical thinking skills in the experimental class compared to the control class.

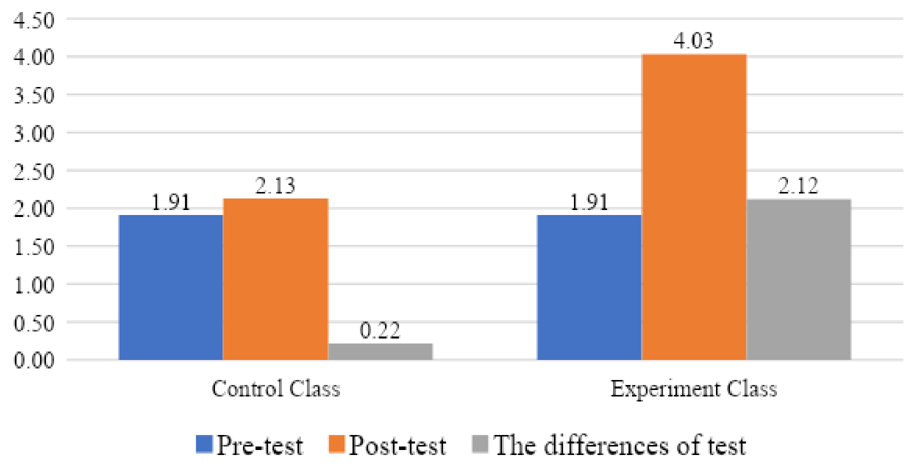

Figure 1
Comparison of critical thinking scores between the control class and the experimental class

The results of the ANCOVA (Table 3) show that there is a significant difference in the score of critical thinking skills in science between the control class and the experimental class (Sig. KELAS <0.05), and the pretest score of critical thinking skills in science between the control class and the experimental class is not significantly different (Sig. KELAS*PRETEST > 0.05).

A significant difference in critical thinking skills in science between the control class and the experimental class is believed to be the effect of the treatment given to the experimental class. This data is also reinforced by how the pretest scores between the two classes (control class and experimental class) show no significant difference. This indicates that students' initial ability in critical thinking skills before the treatment is equal between the control and experimental classes.

Moreover, the significant difference in critical thinking skills scores in science between the control class and the experimental class also indicates that practicing solving HOTS-based science questions effectively improves students' critical thinking skills. Observing the average posttest scores, the experimental class scored double the control class (Table 4).

Table 3
The ANCOVA results of students' critical thinking

Source	Type I Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	153.108[a]	3	51.036	319.702	.000
Intercept	1587.511	1	1587.511	9.945E3	.000
KELAS	153.066	1	153.066	958.841	.000
PRETEST	.042	1	.042	.262	.609
KELAS * PRETEST	.001	1	.001	.004	.951
Error	25.701	161	.160		
Total	1766.320	165			
Corrected Total	178.809	164			
R Squared = .856 (Adjusted R Squared = .854); Dependent Variable: POST-TEST					

The average level of students' critical thinking skills in each aspect (Analytical, Inferential, Evaluating, Induction, and Deduction Skills) between the control and experimental classes also show differences (Table 4). The average posttest score for each aspect of the experimental class is higher (M=4.03) than the control class (M=2.13). These data indicate that giving HOTS-based science questions can improve students' critical thinking skills.

Table 4
Comparison of the average of pretest and posttest scores of critical thinking skills based on skill aspects

Aspects	Control Class		Experiment Class	
	Pretest	Posttest	Pretest	Posttest
Analytical Skill	1.80	2.09	1.81	4.22
Inferential Skill	1.74	1.94	1.75	4.22
Evaluating Skill	2.09	2.29	2.09	3.83
Induction Skill	2.20	2.40	2.20	3.70
Deduction Skill	1.70	1.90	1.71	4.18
Average	1.91	2.13	1.91	4.03

Thus, since there was a difference in critical thinking between the experiment and control class, further analysis was to see whether each critical skill aspect from the posttest between the two groups differs. Table 5 shows the ANOVA test result to see the differences between each critical skill aspect for both groups. From the data, it is indicated that there were no significant differences for all critical skill aspects, including analytical skill, inferential skill, evaluating skill, induction skill, and deduction skill for the experiment group and control group (p=0.996), while based on the posttest scores, the critical thinking between the experiment and control groups is significant (p=0.001).

Table 5
The ANOVA test result for each critical skill aspect

Source	Type II Sum of Squares	df	Mean Square	F	Sig.
Model	103.778[a]	6	17.296	166.488	0.000
Aspects	0.017	4	0.004	0.041	0.996
Class	9.082	1	9.082	87.420	0.001
Error	0.416	4	0.104		
Total	104.194	10			

a. R squared= 0.996 (Adjusted R Squared= 0.990)

DISCUSSION

Globalization changes require all nations to increase their ability to compete in all aspects. One of them is the skill to compete in the field of science. Mastering science well enables a nation to create technology to facilitate a better nation's better life. Critical thinking skills are necessary for mastering science and solving many life problems. Considering the importance of critical thinking skills in science, improving them at the elementary and secondary school levels and even at the university level is urgently needed. One of the efforts is the habituation of students to practice solving HOTS-based science questions.

Higher order thinking skills (HOTs) generate new knowledge through assessment, criticism, and creativity relevant to life outside the classroom (Zohar & David, 2009). HOT varies individually (Lewis & Smith, 1993 in Sasson et al., 2018). Duijzer (2020) argued that what may be considered HOT for an individual may be routine procedures for others. Thus, the application of HOT in the classroom (and what makes students different from lower order thinking activities) also depends on the nature of the task and one's intellectual experience (Alexander et al., 2011). Students' thinking progresses from LOT to HOT as they age, implying that they must have a certain education, experience, practice, resources, and support to develop HOTs (Roets & Maritz, 2017).

The study's findings showed that the increased score of the HOT-based questions test for both the control and experiment occurred. Yet, by using the same test questions, the experimental class has a higher mean score for each aspect of critical skills. It could be defined that the treatment successfully influenced the students in the experiment group. The way the implementation was carried out was that the teacher provided science material first and discussed it. The explanation and discussion were based on the case that the teacher would use to formulate the concept. Conducting discussion was found as one of six syntaxes of Stim-HOTS model applied to improve students' critical thinking skills because this stage had been able to train students' ability to analyze and evaluate concepts learned (Saputri et al., 2019). After students were considered to have understood the concept, the teacher gave them HOTS-based science questions. Widana et al. (2018) reported that using HOTS-based questions can help teachers improve students' critical thinking skills.

A study by Tsaparlis (2020) administered HOT problems that were not given in the previous year and reported that the overall student performance decreased; however, those problems can separate the outstanding from good (ordinary) students. If students are tested throughout the semester with problems containing HOTS, they will gain not only a deep conceptual understanding of the material but also a better memory of the information in the course (Jensen et al., 2014). Another study also found that students critical thinking, helped by their self-efficacy, could influence their thinking abilities, measured using HOTS questions (Syarifah et al., 2019).

This study also found that students from the control or experiment group have the same skill for those five aspects of critical skills. Yet, both classes are significantly different in the overall performance of critical thinking skills. In this case, the practicing of HOTS-based science questions has influenced every aspect of the critical thinking of the students in the experiment class. When viewed from the side of improving the critical thinking skills of participants, this study also supports the results of research from Saputri et al. (2019), which states that HOTS questions can improve students' thinking skills in learning science with various subject levels. Increased mastery of critical thinking also directly affects analytical skills, which can help students map out problems and information needed as capital to solve a problem (Chijioke & Offiah, 2013; Cullen et al., 2018). Taleb and Chadwick (2016) also revealed that critical thinking skills could improve analytical skills. In addition to improving students' analytical skills, critical thinking skills can also improve students' skills to conclude (Cañongo et al., 2020). Inferential skill is very useful for students, especially when they learn to make decisions related to strategies to solve problems (Soto et al., 2019).

Giving HOTS-based science with essay tests has improved students' critical thinking. In her study, Mahanal et al. (2017) explained that to have good critical thinking, students should develop their ability in language use and focus, which is related to providing a rational reason and vibrant argumentation in answering the test. Thus, besides treating students with HOTS-based science questions, appropriate learning strategies (such as cognitive learning), motivation, self-efficacy, encouragement of learning sources exploration, and reading comprehension habits are also suggested to be implemented to improve student's critical thinking skills (Mahanal et al., 2017; Muslem et al., 2017; Purnomo et al., 2021).

Critical thinking skills can provide significant benefits for students, especially in the context of solving problems related to science. This is important because critical thinking skills are needed in 21st-century learning that will help students compete globally (Aslan, 2015). Therefore, the results of this study are significant as a reference for educators in science on how to develop student's critical thinking skills through HOTS-based science questions. In addition, it is expected that the mastery of critical thinking skills in science can be a significant initial capital for a nation to improve its welfare.

CONCLUSION

Based on the objectives and results of this study, it can be concluded that the habituation of HOTS-based science questions can effectively improve students' critical thinking. The critical thinking skills scores between the control and experimental classes are significantly different ($p<0.05$). In addition, the posttest means between the experimental and control classes also significantly differ, with the experimental class scored double the control class. The results of this study are expected to provide an overview and benefits for practitioners of science education to improve critical thinking skills in science using HOTS questions. This research should be further investigated due to the time constraint and the limited number of subjects involved. Therefore, future studies should expand the subject and deepen the analysis with other types of questions. In addition, separating students by their ability is also suggested to see the effect of this HOTS-based science drill and practice. The ability of teachers to understand HOTS is also needed to be investigated in advance.

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