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Empowering critical thinking skills on different academic levels through discovery-based multiple representation learning

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ABSTRACT

Critical Thinking Skills (CTSs) are necessary for science mastery. To help the students develop their CTSs, discovery-based learning and student-centered activities may be beneficial. This study aims at investigating: (1) the effects of the discovery-based multiple representation learning (DMRL) model on CTSs; (2) the effects of different academic achievements on CTSs; and (3) the interaction between a learning model and types of different academic achievement on CTSs. The participants were 162 students, grade 7th from 3 public schools in Sleman, Indonesia. They were classified into 54 students with exceptional academic achievement, 48 students with average academic achievement, and 60 students with below-average intellectual ability. We used an essay test to collect data on CTSs utilizing a non-equivalent control group design with pretest and posttest. ANCOVA was used to examine the data (p = .05). The results of the study show that: (1) The DMRL had a high potential to improve the students' CTSs; (2) The students with HA had the highest CTSs; (3) there is an interaction effect between the learning model and the different types of achievement on CTS. As a result, we conclude that the DMRL was effective in closing the CTSs discrepancies between students with high, moderate, and poor academic achievement outcomes.

Keywords: critical thinking skills, different achievements, discovery, multiple representations

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INTRODUCTION

Critical thinking abilities are a subset of higher-order thinking skills (HOTS) needed for making purposeful, reflective, and fair-minded judgments about whether to trust or predict future practical issues. As a result, critical thinking becomes increasingly crucial as real-world situations get more sophisticated in today's world (Mutakinati et al., 2018). Students' CTSs and HOTS should be optimally empowered in learning. Critical thinking skills have a long-term benefit in the field of education as they can assist students in solving problems encountered in the learning process and their application in everyday life (Kaddoura, 2011). Meanwhile, the CTSs' short-term purpose in the learning process is to help students improve their conceptual knowledge (Khasanah et al., 2017), especially in the natural sciences learning materials. In other words, the students' CTSs are needed to overcome problems in everyday life.

To teach science effectively, all three facets of scientific product, methodology, and attitude must be taught to students (Chiappetta & Koballa, 2010). When the learning process is process-oriented, those three aspects will be acquired properly. Natural science learning that is process-oriented enables students to conduct scientific investigations and create scientific products in the manner of a professional scientist. Students can enhance their critical thinking abilities and build scientific attitudes through scientific activities (Retnawati et al., 2018; Suryawati & Osman, 2017; Wartono et al., 2018).

Numerous studies demonstrate that Indonesian students' CTSs are very low (Abdurrahman et al., 2019; Hobri et al., 2018; Mahanal et al., 2017; Tanudjaya & Doorman, 2020; Zhou et al., 2013). According to the findings of the most recent PISA survey, the Indonesian scientific literacy score is 396 (OECD, 2019). This number experienced a slight decrease from 2015, which amounted to 403. This placed Indonesia ranked 70 out of 78 participating countries. This figure is still far from the average science score of all participants, namely 489. The result demonstrates that the quality of science education in Indonesia, particularly scientific literacy and critical thinking skills, is still significantly lower than in OECD countries.

Additionally, the apparent CTSs disparities amongst students with varying academic attainment must be addressed promptly. The academic abilities of students can be characterized as a high academic (HA), middle academic (MA), or low academic (LA) (Özgüç & Cavkaytar, 2015). Academic attainment varies significantly among students due to the frequent nonlinearity of their age and IQ (Corebima, 2007; Jeynes, 2015). Academic success is determined not just by academic aptitude but also by a range of other criteria, such as the length of the study period (Ozden, 2008). Academic achievement gaps between children with HA, MA, and LA achievement can be decreased if kids with LA achievement are given the time and resources to study according to their unique needs and talents (Corebima, 2007; Haak et al., 2011). All students in schools have the same amount of study time, which results in academic success differences. As a result, a teaching model that addresses this issue is critical.

Critical thinking talents can be taught through instructional techniques that place a premium on scientific work (Gormally et al., 2009). A strategy that is appropriate is discovery-based learning. The syntax for discovery-based learning is based on the methods of the scientific method (Arends, 2012; Veermans, 2002). Discovery-based learning is beneficial for developing students' critical thinking abilities (Akinbobola & Afolabi, 2010; Großmann & Wilde, 2019). Multiple representation-based education can be used to close the gap between HA and LA students' critical thinking abilities (Çetin, & Aydın, 2020). Multiple representation-based instructions optimize the scaffolding utilized with HA students and can be extended to teach LA students via discussion, tutorial, and peer teaching. This study utilized a variety of representational styles, including photographs, physical models, manipulative models, real-world scenarios, metaphors, conversational language, and written symbols.

Integrating Discovery-based and Multiple Representational Learning (abbreviated as DMRL) is believed to be critical for closing the CTSs gaps across HA, MA, and LA students. Implementing Discovery Learning (DL) is less effective in solved learning gaps than combining it with Multiple Representational Learning (MRL) (Syahmel & Jumadi, 2019). On the other hand, implementing MRL without DL does not adequately support students in practicing scientific method, as MRL was not created to educate students scientific method (Chen & Harrison, 1988). Whereas the scientific method is an excellent tool for developing critical thinking abilities. DMRL, as a hybrid of discovery-based and model-based learning, possesses the properties of both methodologies. The distinctive aspect of discovery-based learning is that it imparts knowledge of the scientific method. MRL has a significant scaffolding aspect in the form of various representations that has been shown to be effective not only in lowering academic achievement gaps amongst HA, MA, and LA students but also in empowering CTSs students.

Existing research on the application of CTSs has primarily focused on a specific type of learning model, such as discovery-based, problem-based, or DMRL learning (Siew, Chong & Lee, 2015; Yusuf, Tüysüz, & Kuşdemir, 2013). According to Gozuyesil & Dikici (2014), if a group of students with nearly equal academic abilities is taught in the same way and for the same amount of time, the learning outcomes will follow a normal distribution curve. The gaps in learning outcomes between HA, MA, and LA students can be reduced by customizing the amount of time allocated to LA students to meet their unique demands. Because the length of learning is identical for HA, MA, and LA students, the deployment of a single learning model may result in CTSs gaps between them. Due to its collaborative nature, DMRL is regarded as a viable learning technique for resolving time-related difficulties through scaffolding in the form of numerous representations and peer tutoring activities.

As a result of the foregoing, it is required to undertake research to determine whether DMRL can close academic achievement inequalities between HA, MA, and LA students and is more successful than conventional learning. The aims of research are to find out: 1) effects of DMRL model on CTSs; 2) effects of different academic achievement on CTSs; and 3) interaction effects between the learning model and different types of academic achievement on CTSs.

METHOD

Design

The study is a quasi-experimental design with a nonequivalent control group. Pre- and post-tests were used to compare the data. From February to April 2021, the research samples were treated for three months, and the CTSs were assessed after the treatment. To account for the variance in the original CTSs between research samples, we used pre-test scores as covariates. Table 1 illustrates the research design.

Table 1. Research design

Cluster	Pre-test	Variable	Post-test
C1	CTCs	X1Y1	CTCs
C2	CTCs	X2Y1	CTCs
C3	CTCs	X1Y2	CTCs
C4	CTCs	X2Y2	CTCs
C5	CTCs	X1Y3	CTCs
C6	CTCs	X2Y3	CTCs

CTSs: Critical Thinking Skills, X1: DMRL, X2: discovery learning, Y1: higher academic achievement, Y2: middle academic achievement, Y3: lower academic achievement

The research population was seventh graders that learn about conservation from 3 public junior high schools in Sleman, Indonesia. Three schools of low, middle, and high-quality schools had been selected using a stratified cluster random sampling method, in which random samples were taken from three groups of higher-quality schools (1 school with 2 classes), middle-quality schools (1 school with 2 classes), and lower quality schools (1 school with 2 classes). The quality of the schools was determined by the students' average scores in the national examinations. The data of national examination scores were taken from the Center of Assessment Education of Indonesia. The participants in each school were grouped into two categories using the DMRL model and discovery-based learning. The total number of research samples was 162 students consisting of 54 students with higher academic achievement (HA), 48 students with middle academic achievement (MA), and 60 students with lower academic achievement (LA). Students were categorized according to their academic abilities, which were determined using the results of their elementary school's national examinations. The distribution of the research sample is presented in Table 2.

Table 2. Sample distribution

School	Class	Σ HA	Σ MA	Σ LA	Learning Model	National Examination Score
A	7 C	26	-	-	DMRL	62.75-71.56
A	7 D	28	-	-	Discovery	62.75-71.56
B	7 A	-	24	-	DMRL	57.67-62.10
B	7 C	-	24	-	Discovery	57.67-62.10
C	7 A	-	-	31	DMRL	51.30-52.91
C	7 B	-	-	29	Discovery	51.30-52.91

Although all students in each school were considered collectively, data were evaluated on an individual basis. Before conducting treatments at all selected schools, the researcher discussed the strategy with participating students and teachers and obtained authorization from the Regional Educational Board of Yogyakarta Province, school administration, teachers, and students.

The students' CTSs were determined through essay assessments. The Watson-Glaser, Facione, and Ennis indicators were used to collect data on critical thinking abilities. Before conducting the evaluation, the validity and reliability of the instrument were determined. Expert judgments and an empirical test were used to determine the validity. Seven experts evaluated the evaluation to ensure that it was appropriate for measuring CTSs indicators and that it was compatible with the learning material.

After analysis, the experts concluded that the evaluation was legitimate, with an Aiken-V validity rating of .85. Following the expert judgment, an empirical test was done. As a pilot, the examination was administered to 175 grade 8 students at a public middle school in Sleman, Indonesia. The empirical test revealed that the assessment was valid with the Outfit *t* values more than -2.00 but less than +2.00. Cronbach's alpha was used to determine the assessment's dependability index. As a result of the foregoing, it is required to undertake research to determine whether DMRL can minimize academic success gaps between HA, MA, and LA students and is more successful than conventional learning.

The ANCOVA test was used to analyze the data. The normality and homogeneity tests were conducted before that. To account for differences in critical thinking abilities between research samples, pre-test or baseline scores on the students' CTSs were employed as variables. To determine the normality of the data, the Kolmogorov-Smirnov parametric statistical analysis was used. The pre-and post-test scores were both greater than 0.05, indicating that they were in the normal range, however, Levene's homogeneity test indicated that homogenous variants were at 0.36.

FINDING AND DISCUSSION

Finding

The new model of learning, dubbed DMRL, is built via a series of processes and procedures. Multiple Representation learning is combined with discovery-based learning. The repetition phase of discovery-based learning is utilized to bolster the MR model's operations. The outline of DMRL procedures is (1) phase 1: orientation, (2) phase 2: simulation-based multiple representations, (3) phase 3: identification and problem statement, (4) phase 4: exploration, (5) phase 5: literacy data, (6) phase 6: present and verification, and (7) phase 7: evaluation. The procedures in the DMRL model are visualized in Table 3.

Table 4 contains the findings of the analysis of covariance for critical thinking skills and learning model, as well as the interaction effect between learning model and level academic accomplishment.

According to Table 4, the p-value for academic achievement level students was 0.000 (<0.05), indicating that the academic achievement level of students has a significant effect on their critical thinking capabilities.

The analysis of covariance assumed that there were no significant group differences at the pretest; therefore, the first step was looking at the p values of the pretest as the covariate. Table 4 showed that the p-value of the pre-test data source was 0.000 (<.05), which indicated that the sample had a significant difference for the baseline. It means, most of the research participants experienced critical thinking skill improvement. Then, the Model data source obtained the p values of 0.000 (<.05), this suggests that integrating diverse instructional styles has a major impact on students' critical thinking abilities. The contribution of each learning paradigm to the development of student's critical thinking abilities shown in Table 5.

As shown in Table 5, the effect of DMRL is considerably different from that of discovery-based learning, implying that the DMRL model is regarded to be more effective in developing students' critical thinking abilities than the discovery-based learning model. Additionally, differences in students' critical thinking abilities between the DMRL and DL classes were studied across all critical thinking domains. Figure 1 visualizes the score differences of each critical thinking skill aspect.

Table 6 summarizes the average adjusted score for critical thinking abilities across various academic achievements.

Table 3. Procedures of DMRL model

Phase	Teacher Activity	Students Activity
1	• The teacher give motivation, apperceptions, and learning purposes • The teacher forms heterogenic groups	• The students listening and answering questions by the teacher • The students are divided into groups by the teacher.
2	• The teacher presents problem-based multiple representation	• The student attention by presented the teacher
3	• The teacher guides students in determining and formulating problems.	• The students find and generate the problems
4	• The teacher helps the student's exploration to collect data	• The students making exploration to collect data
5	• The teacher guides the students through the data analysis process. • The teacher guides the students to draw a conclusion that answering the problems.	• The students analyze the data • The student draws a conclusion that answering the problems
6	• The teacher invites each group to deliver the outcome of their conversation in front of the class.	• Each group's members deliver the outcome of the conversation in front of the class.
7	• The teacher gives evaluation/ recognition to each group • The teacher hands out individual assignment	• Each group receives the teacher evaluation/recognition for their hard work. • The students work on the individual assignment

Table 4. Analysis of covariance of the effect different learning models on CTSs

Source	Sum of Squares	*df*	Mean Square	*p*
Intercept	19343.991	1	19343.991	0.000
Pre-test	21938.852	1	21938.852	0.000
Learning Model	2851.994	1	2851.994	0.000
Level of academic achievement	992.226	2	496.113	0.000
Learning model* Level of academic achievement	962.636	2	481.318	0.000
Error	5981.379	149	40.143	
Total	682202.170	162		
Corrected Total	46605.364	161		

R Squared = .872 (Adjusted R Squared = 0.861)

Table 5. Critical thinking skills on each learning model

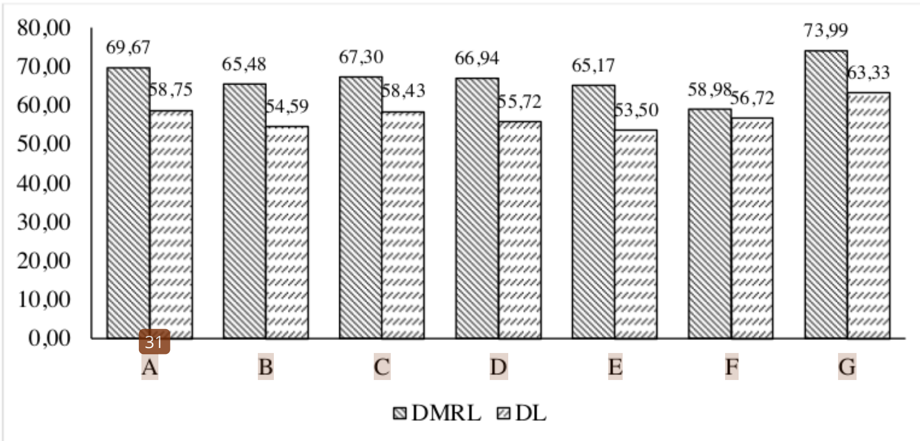
Learning Model	XCTSs	YCTSs	Difference	CTSs-cor
DMRL	41.26	68.14	26.88	66.79
DL	40.14	57.82	17.68	57.29

Table 6. Critical thinking skills in different level of academic achievement

Level of academic achievement	XCTSs	YCTSs	Difference	CTSs-cor
Low Achievement (LA)	20.62	42.04	21.42	41.72
Middle Achievement (MA)	40.36	63.23	22.87	63.01
High Achievement (HA)	60.17	80.91	20.74	80.56

Table 7. Interactions between instructional models and academic achievement

Learning Model	Level of Academic Achievement	XCTSs	YCTSs	Difference	CTSs-cor
DMRL	Low Achievement (LA)	22.27	46.10	23.83	45.70
	Middle Achievement (MA)	40.92	69.20	28.28	68.24
	High Achievement (HA)	60.74	85.92	25.18	85.12
DL	Low Achievement (LA)	18.97	37.97	19.00	36.99
	Middle Achievement (MA)	39.31	57.00	17.69	55.87
	High Achievement (HA)	59.61	75.91	16.30	75.21



Description: A: Clarity assumption, B: Interpretation, C: Analysis, D: Evaluation, E: Reason, F: Inference, G: Self-regulation

Figure 1. The Differences Aspect of Critical Thinking Skills Between the DMRL and DL

Figure 1 informs that the students' self-regulation skills in the DMRL teaching model obtained the highest score than others, whereas the reasoning skill in the DMRL teaching model had the lowest score. Overall, the students' ability to clarity assumptions, interpret, analyze, evaluate, reason, inference, and self-regulation in the DMRL class was higher than in the DL class.

According to Table 6, the average adjusted score for critical thinking skills is 80.56 for HA students, 63.01 for MA students, and 41.72 for LA students. The capabilities that HA students possess are distinct from those that MA and LA students possess. Students in HA have superior critical thinking abilities to those in MA and LA.

According to Table 4, the interaction between different learning models has a significant effect on students' academic accomplishment and critical thinking skills, with p = .00, less than the alpha level of .05. This indicates that the relationship between various learning models and students' academic accomplishment has a major effect on students' critical thinking abilities. The relationship between learning models and academic accomplishment, as well as its effect on students' critical thinking abilities, is demonstrated in Table 7 by the LSD test result.

The results of the DMRL model applied to HA and MA students and the DL model applied to HA students are considerably different from the results of the DMRL model applied to HA and MA students, the DL model applied to HA and LA students, and the DL model applied to HA and LA students, respectively.

The results of applying the DMRL model to LA students are significantly different from the results of using the DMRL model to HA and LA students. The DMRL model's outcomes for HA students are notably different from the DL model's outcomes for HA and LA students. The DMRL model's outcomes for LA students are significantly different from the DL model's outcomes for LA students, but only marginally different from the DL model's outcomes for HA students. The DMRL model applied to HA and MA students has a comparable effect on students' science process skills as the DL model used to HA students. The DMRL model, when applied to HA, MA, and LA students, is more effective in improving students' science process abilities than the DL model. After learning to use DL models, HA and LA students demonstrated an improvement in their science process skills.

Discussion

The collaborative group formation phase for discovery work, which places the heterogeneous academic level of students, made an obvious difference for the DMRL model compared to others (Chusni et al., 2020). In addition, the teachers also provided the materials of conservation of the sand mining of Mount Merapi phenomena which became the investigating issue such as Merapi sand mineral resources, interactions between humans and the environment around mining, environmental pollution issues, and environmental conservation around sand mining. The cases in the form of multiple representations were able to stimulate the students' curiosity before the learning began. The scaffolding process worked so well that each group member with a higher academic level was able to guide the middle and lower academic members to achieve Zone of Proximal Development (Haruehansawasin & Kiattikomol, 2018; Tabak & Kyza, 2018; van de Pol et al., 2019). Scaffolding supported the students at the beginning of a lesson and then gradually turned over the responsibility of them to operate on their own (Gillies & Haynes, 2011). Peer tutors among group members in the DMRL model were more active than the discovery-based learning, and conventional class. The scaffolding process between peers has fostered each students' critical thinking skills, especially self-regulation which score higher in the DMRL class (Garrison & Akyol, 2015).

The increasing aspect of reason indicated that the students started to be trained to describe the information illustrating the content of the information clearly (Facione, 2011). After the treatment using both models, the students were able to reason the procedures for the land conservation after sand mining, identify the impact that is generated from sand mining directly and indirectly on the environment, and provide the experimental results, such as explaining the influence of land layer composition against the process of landslides. A good reason skill will be seen when a student expresses her opinion with confidence (Zhou et al., 2013). Their activities of constructing the concepts, drawing a conclusion, presenting to others have been proven to improve students' critical thinking skills, especially the reason aspect (Forawi, 2016; Sampson & Clark, 2008).

The phase present and verification required the students to act as the presenter in charge of explaining the experimental/ exploration results. The students presented the various components of mineral resources produced from Mount Merapi, the principle of human interaction with the environment, and other concepts obtained during the scientific work. Both learning models have stages that enable students to communicate the experimental/ exploration results. However, the collaborative group of DMRL learning tended to make the lower academic group members became less confident when explaining and interpreting something so that students were more likely to have a higher academic member to explain it. The lack of confidence resulted in the less optimal reasoning skill. (Damavandi & Kashani, 2010; Ramli et al., 2017).

The results of this research showed that there was a difference in critical thinking skills between the DMRL and DL models. Thus, it is parallel with the previous research stating that the DMRL has a higher potential to enhance the learning process than the DL (Chusni et al., 2021). However, it should be kept in mind that these results are specific to study the effect of different teaching models on students' critical thinking skills. The differences between DMRL and DL were seen from the differences in their activities of scientific work. The collaborative team fostered the low academic students to determine their scaffolding process since peer tutoring provided longer study time for low academic students (Wass et al., 2011). Adequate study time can improve the critical thinking skills of low academic students. Based on these research results, the researcher recommended implementing the DMRL model, especially for the scaffolding process by peer tutoring to nurture students' critical thinking skills. Each of critical thinking skill indicator needs to be trained as it is one of the fundamental skills to mastery learning in science and implement it in everyday life.

CONCLUSION

The implementation of DMRL had a significant effect on the CTSs of 7th-grade students at junior high school in Sleman. The level of students' academic achievement significantly affects the critical thinking skills of students. There was an interaction between the implementation of the DMRL learning model and the different levels of academic achievement on the critical thinking of the students. This research's result suggests the right pattern of scientific work begins with students observing problems, identifying and formulating problems, exploration/ experiment, collecting and analyzing data, communicating, and then making conclusions, if students can carry out scientific work appropriately, then the critical thinking skills can be empowered optimally using DMRL learning. The results of this study can be argued that DMRL will effectively close the gap between high, middle, and low academic achievement students. The research may be continued on the subject of science or other subjects at primary or middle schools. Future research can also focus on other thinking skills such as creativity, problem-solving, scientific literation, and others.

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