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Effectiveness of discovery learning-based multiple representation module on enhancing the critical thinking skills of the students with high and low science process skills

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Abstract: The study examines the effectiveness of a multiple representation module based on discovery learning in enhancing students' critical thinking. The study used a quasi-experiment design with a 2×2 design analysis. The subjects were 114 students with high and low science process skills from Sleman district's class VII Islamic Junior High Schools. The sample was separated into two groups: a control group that utilized conventional modules and an experimental group that utilized a Discovery Learning-based Multiple Representation module; each sample group was further broken into two groups with high and low science process skills. The test of critical thinking skills was adopted by Facione (2011). Another instrument was an observation sheet to observe science process abilities. The data analysis revealed that implementing the Discovery Learning-based Multiple Representation modules improved students' critical thinking abilities. Not only did student science process abilities influence their critical thinking abilities, but there was also an interaction between the module and student science process abilities.

Kata Kunci: discovery learning, learning module, multiple representations, science process skills

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INTRODUCTION

Critical Thinking Issue

Critical thinking abilities are a subset of higher-order thinking abilities (HOTS) needed to make purposeful, reflective, and fair judgments about whether to trust or future practical issues. As a result, critical thinking skills (CTSs) become increasingly crucial as real-world situations get more sophisticated in today's world. (Mutakinati et al., 2018). Students' CTSs and HOTS have to be optimally empowered in school learnings. CTSs have a long-term benefit in 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 educational process is to assist students in improving their conceptual knowledge (Khasanah et al., 2017), especially in the natural sciences material. In other words, the students' CTSs are needed to overcome problems in everyday life.

In teaching science effectively, students must be taught all three facets of scientific product, methodology, and attitude (Chiappetta & Koballa, 2010). The three aspects will be acquired properly when the learning process is process-oriented. 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 CTSs and build scientific attitudes through scientific activities (Retnawati et al., 2018; Suryawati & Osman, 2017; Wartono et al., 2017).

In Indonesia, natural science education is focused chiefly on remembering scientific concepts. Natural science teaching success is often judged by the number of scientific products (concepts, ideas, and laws) students correctly recognize and memorize. Students are not given sufficient opportunities to grow their CTSs. Students study in teacher-centered classrooms, where the teacher is the primary source of knowledge and maintains complete control over the classroom and its activities (Lancaster, 2017).

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Natural science education focusing on remembering science items will result in low CTSs and negative attitudes toward science among students. Students will develop a habit of thinking rationally and methodically as a result of learning CTSs and will be capable of resolving issues that arise on a regular basis in their daily lives (Chen & Hu, 2018; Kavenuke et al., 2020).

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 most recent PISA survey findings, the Indonesian scientific literacy score is 396 (OECD, 2019). This number experienced a slight decrease from 2015, which amounted to 403. It 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 CTSs, is still significantly lower than in OECD countries.

This CTSs issue has become a focus of recent research, and the educational system must shift toward a more explicitly inclusive model of thinking capacity learning in schools (Dipalaya et al., 2016). It is also shown by Heong et al. (2012), who asserts that the analysis skill is the least developed of the five components of Bloom's taxonomy thinking capacity. Comparable to a study conducted by Çığrık & Ergül (2010), by 13.69 percent, the CTSs contribute significantly to student accomplishment, which includes reasoning and explanatory skills.

CTSs could be enhanced by selecting the most appropriate tactics, approaches, methods, models, and teaching materials, for example, material qualities and student characteristics (Areesophonpichet, 2013; Nuangchalerm & Thammasena, 2009). According to the facts in the case, the school-based learning method had not yet adequately taught the CTSs. The learning process was occasionally conducted in a semi-traditional method. Due to the student's inability to form concepts in a semi-traditional method, the training of CTSs did not operate optimally (Chusni et al., 2020). According to (Silberman, 1996; Chusni et al. 2021; Veermans, 2002), discovery learning was a successful learning methodology for training the CTSs by maximizing the concept construction processes.

Discovery Learning

The discovery learning model was an active learning instructional approach based on understanding cognitive processes involving comprehension, knowledge acquisition, dedication, enthusiasm, and assignment (Arends, 2012). Students were asked to study independently, explore their knowledge from various sources, focus on an observable problem, experiment with building concepts and applying those concepts to real-world issues under the Discovery Learning paradigm (Bano et al., 2019). Students were not simply passive recipients of verbal explanations from the teacher but were also autonomously identifying the subject's core so that all of the student's actions were geared toward generating knowledge through inquiry.

The limited time for problem-solving activities and concept creation was a shortcoming of the classroom-based Discovery Learning paradigm. Students with a lesser academic background required more time to complete the assignment than students with a better academic background (Prayitno et al., 2017). It would be impossible to teach CTSs of lower academic students merely by applying the learning model. As a result, a teaching module comprised entirely of Discovery Learning components was necessary that could be used independently by students at any time and from any location without regard for time constraints, thereby minimizing the gap in CTS training between Students at a higher academic level and students at a lower intellectual level.

Multiple Representation Module

Using multiple representation modules will also attract students' interest in learning. Hand & Prain (2012) states that scientific writing will not be interesting if it only consists of verbal only, so it requires information in other forms such as pictures or graphics, to be interesting. Representation is essential for students to question, observe, describe, discuss, explain, and debate (Kozma, 2012). Multiple (external) representations can be advantageous when people are learning complicated new concepts (Ainsworth, 2006). The existence of a variety of qualitative representations, such as diagrams, alternatively, in some cases, graphical representations, assists students in thinking qualitatively about physical processes and identifying patterns in data without requiring them to perform complicated mathematical computations (Etkina et al., 2006).

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Discovery Learning-based Multiple Representation Module

Discovery Learning-based Multiple Representation (DLMR) implemented the module's integrated Discovery Learning (DL) concept. Daryanto (2013) stated that a module was classified as teaching material capable of teaching students to learn independently and without interference from other parties, allowing student learning time to be extended outside the classroom. The DLMR model was developed as an integrated module of all Discovery Learning activities such as orientation, stimulation-based multiple representation, and identification, and This enables students to practice their CTSs freely (Chusni et al., 2020). Thus, a module combined with a DL model could optimally practice CTSs of both upper and lower academic students.

The steps of activities in the module's DLMR comprised the following: 1) orientation stage, the students listening and answering questions by the teacher apperception and learning purposes; 2) stimulation-based multiple representation learning stages, the student attention to scientific phenomena by presented the teacher, 3) identification and problem statement stage, the students find and generate from the problems in the previous stage, 4) During the exploration stage, students were encouraged to use all five senses to notice the challenges presented and then study various related sources to pique their curiosity, which resulted in the development of a capacity for high-level thinking. The exploration stage allowed kids with limited science process skills to construct concepts by connecting previously owned information from daily life. 5) At the literacy data level, students considered formulating solutions to problems and conducting examinations. 6) During the present and verification stages, Students accepted the challenge of contrasting points of view and demonstrating the superiority of each point of view through scientific evidence. This exchange of viewpoints has the potential to deepen understanding and create opportunities for students to develop ideas and enhance their CTSs. 7) The evaluation stage allowed students to apply their newly acquired concepts to solve issues. The DLMR stages were designed to assist students with solid and weak science process abilities in obtaining new knowledge about the issue under consideration.

Examining the module teaching materials at the Islamic Junior High School in the Sleman area revealed that training in all facets of CTSs remained deficient—the ability to interpret information scores 17%. The ability to identify similarities and differences between reality and the information presented scores 48%. the ability to develop reasons gets a score of 49%. The ability to describe the relationship between phrases or components of an idea to conclude scores 38%. The fact that the components of these CTSs remained low demonstrated the importance of the activity-based training module for training the CTSs entrusted to the module via the DL model syntax to be used as a learning source.

In contrast, the success of teaching materials in the learning process was strongly related to the student's science process (SSP) abilities/skills (Aktamis & Ergin, 2008; Mbewe et al., 2010). The exercises designed to develop students' scientific process abilities are determined mainly by the student's enthusiasm to study (Kohl et al., 2007; Schumacher et al., 2013). The factors that influenced the various degrees of students' motivation to learn were primarily related to the state of the household and a lack of students' curiosity, which resulted in a lack of interest in learning. The incentive for learning was for students to have a positive attitude and a sense of commitment to engage in and be interested in activities. Thus, students with a high degree of excitement for learning demonstrate a greater propensity to learn than those with a low degree of learning (Wigfield et al., 2009). In education, motivation has been defined as a personal investment (Alexander & Murphy, 1998) or a "stable evaluative bias toward a certain domain" (Schiefele, 1999).

Hence, this study was necessary to ascertain (1) the effectiveness of the discovery learning-based multiple representation module on students' critical thinking abilities, (2) the influence of science process skills on students' critical thinking abilities, and (3) the effect of module interaction on students' critical thinking abilities. This study was prepared for implementation in proper and non-proper laboratory schools.

METHOD

Research Design

This study aimed to determine the efficacy of DLMR modules on students' critical thinking abilities, the influence of science process skills on students' critical thinking abilities, and the interaction

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of modules and science process skills on students' critical thinking abilities. Before this research, the DLMR modules were developed using the research and development (R&D) process (Borg & Gall, 1983). The independent variables in this study consist of Multiple Representations based on Discovery Learning and conventional modules, which function as independent variables. At the same time, the dependent variable is students' critical thinking skills. Students' ability to process scientific information becomes a moderator variable to the number of variables and the objectives to be accomplished. A 22-factorial design was utilized (Creswel, 2013). The use of science process abilities as a moderator variable was motivated by the characteristic of the curriculum that utilized a scientific activity approach. As a result, the students have the required incentive to do scientific research. The cause was substantiated by empirical data from reading motivation regression analysis. The regression analysis revealed an r-square of 0.872, indicating that science process skills might predict students' critical thinking ability when exposed to different modules. The first factor was the module for Multiple Representations based on Discovery Learning and the traditional module. The second component was SSP abilities, classified as high or low. The design of this study is shown in Table 1.

Table 1. Factorial Design 2×2

		Discovery Learning-based Multiple Representation (X_1)	Conventional (X_2)
Science Process Skills	High (Y_1)	X_1Y_1	X_2Y_1
	Low (Y_2)	X_1Y_2	X_2Y_2

X_1 is Discovery learning-based multiple representation module; X_2 is a Conventional module; Y_1 is High Ability; Y_2 is Low Ability; X_1Y_1 is Students' CTSs with high SSP use the discovery learning-based multiple representation module. X_1Y_2 students CTSs with low SSP use the discovery learning-based multiple representation module. X_2Y_1 is Students CTSs with high SSP use the conventional module, and X_2Y_2 is Students CTSs with low SSP use the conventional module.

Data Analysis

The analysis of the research objective made use of covariance analysis (ANCOVA). By utilizing Ancova to analyze the data, one can ascertain the influence of independent variables on dependent variables. Additionally, to ascertain the dependent variable's influence through the moderator variable and then to find out the interaction between the independent and moderator variables through the dependent variable in one of the analysis activities.

Sample

This research was conducted at Islamic Junior High School in Sleman, Indonesia, in the academic year of 2020/2021, on 114 class VII students divided into fourth classes. Random sampling was conducted by an intact group methodology of dividing sample classes into two groups according to the research that requires treatment in the form of a module.

Students in each sample class were grouped into high science process skills (HSPS) and soft science process skills (LSPS). Students in each sample class were classified according to their perceived importance of science process skills. According to the science process skills assessment results, there were 28 students with HSPS and 29 with LSPS in the control class, then 26 HSPS students and 31 LSPS students in the experiment class. Thus, the total sample was 114 students. The research sample is illustrated in Table 2.

Table 2. Sample Distribution

Class	Σ student HSPS	Σ Student LSPS	Treatment	Science Process Skills Score
Experiment	26	-	Discovery Learning-based Multiple Representation Module	62.75-71.56
	-	31		51.30-52.91
Control	28	-	Conventional module	62.75-71.56
	-	29		51.30-52.91

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Instrument

The instruments used to collect data for this study were essay analysis, a critical thinking skills test, and a test of science process abilities. The test used in this study was a written one constructed using Facione's (2011) critical thinking skills rubric, which includes six indicators that are (1) interpretation, (2) analysis of ideas, (3) inferring findings, (4) evaluating the similarities and differences between reality and the information presented, and (5) developing explanations. Before collecting data on students' CTSs, the test instrument was validated by an expert validator and an education and science lecturer as content validity. The following instrument was a scientific process skill. This sheet was used to assess SSP skills during the learning process.

The methodologies for data analysis include descriptive and inferential statistical analysis. The descriptive statistical analysis was used to characterize or explain the data collected on students' critical thinking and SSP while implementing the Discovery Learning-based Multiple Representation and standard modules. At the same time, inferential statistical analysis was used to analyze the data collected from the critical thinking skills test results. This study used the Ancova test to evaluate the data, with the pre-test score as a covariate. Before conducting the Ancova test, a normality and homogeneity check was performed using the Lilliefors and Levene tests, respectively. All tests were conducted using SPSS.

Treatment

Based on discovery learning, Multiple Representation was a module based on a DLMR syntax that required students to participate actively in learning by connecting new ideas to prior knowledge. It included learning objectives, instructional materials, methods, tools, or media, and instructional and assessment resources.

Seven components comprised the syntax of the DLMR model: orientation, stimulation-based multiple representation, identification, and problem description, investigation, literacy data, presentation and verification, and assessment (Chusni et al., 2020).

During the orientation stage, students listen to and respond to questions from the teacher regarding their perception and learning objectives. During the stimulation-based multiple representation stages, students were encouraged to use all five senses to pique their curiosity, which resulted in developing a high-level reasoning ability.

In the identification and problem statement stages, students considered developing concepts for solving difficulties and conducting the experiment. The exploration stage allowed kids with limited science process skills to construct concepts by connecting previously owned information from daily life.

According to the literacy data, students considered developing ideas to solve problems and conducting examinations. At the present and verification stages, students embraced the cognitive challenge of contrasting viewpoints and demonstrated each perspective's superiority with scientific facts. This exchange of viewpoints has the potential to expand knowledge and create opportunities for students to develop ideas.

At the concept evaluation step, students were allowed to answer problems using their acquired concepts. The model's syntax could inspire students to engage in higher-order thinking processes, implying that the DLMR model-integrated modules could facilitate the development of critical thinking skills. The activities of learning can be seen in Table 3.

Table 3. The Discovery Learning-based Multiple Representation Syntax to Activities in the Module

Syntax	Teacher Activity	Students Activity
Orientation	• The teacher gives motivation, apperceptions, and learning purposes • The teacher forms heterogenic groups	• The students listen and answer questions from the teacher • The students are divided into groups by the teacher.
Stimulation-based Multiple Representation	• The teacher presents problem-based multiple representations	• The student's attention by presented to the teacher
Identification and Problem Statement	• The teacher guides students in determining and formulating problems.	• The students find and generate the problems

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Syntax	Teacher Activity	Students Activity
Exploration	• The teacher helps the students explore to collect data • The teacher guides the students through the data analysis process.	• The students making exploration to collect data • The students analyze the data
Literacy Data	• The teacher guides the students to conclude by answering the problems.	• The student draws a conclusion that answering the problems
Present and Verification	• 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.
Evaluation	• The teacher gives evaluation/ recognition to each group • The teacher hands out an individual assignment	• Each group receives the teacher evaluation/recognition for their hard work. • The students work on the individual assignment

RESULT AND DISCUSSION

the results of the analysis, the normality test for the student's critical thinking abilities was 0.200. As a result, the sample from class VII was normally distributed. Additionally, the homogeneity test revealed a value of p.> .05, which was 0.43. It suggested that the data variation on the student's critical thinking abilities was constant or homogeneous. According to the findings, the data from this study met the criteria for the Ancova parametric statistical test.

The ANCOVA test findings for critical thinking abilities within the learning module, science process skills, and the relationship between learning modules and science process skills are shown in Table 4.

Table 4. Output of Ancova Test on Students' CTSs

Source	Sum of Squares	*df*	Mean Square	*F*	*p*
Corrected Model	39109.426[a]	4	9777.356	204.783	.000
Intercept	12566.906	1	12566.906	263.209	.000
Modules	1734.857	1	1734.857	36.336	.000
Pre-test	23172.665	1	23172.665	48.344	.000
Science Process Skills	767.866	1	767.866	16.082	.000
Module* Science Process Skills	345.812	2	34.812	7.242	.008
Error	7495.937	110	47.744		
Total	682202.169	114			
Corrected Total	46605.363	113			

R Squared = .839 (Adjusted R Squared = .835)

The sig. Value found in the data source model was .000 (< .05), indicating a difference in critical thinking abilities between the Discovery Learning-based Multiple Representation module and the conventional modules. As a result, it was discovered that the DLMR module substantially impacted students' critical thinking abilities.

Scientific method-based learning is proven effective in teaching higher-order thinking skills (Ahmad & Mahmood, 2010). Students with higher-order thinking skills are believed to have better science process skills than those with lower-order thinking. It aligns with the argument (Hugerat & Kortam, 2014) that using higher order thinking skills such as problem-solving, questioning, reasoning, communication, and conceptualization will positively contribute to student achievement and science process skills. Edwards & Briers (2000) argues that critical, logical, and rational thinking is needed to help students master science process skills.

Conventional teaching models lead students to memorize all the knowledge they receive, which limits the development of their science process skills. Edwards & Briers (2000) stated that science process skills could be mastered by students who have developed higher-order thinking skills. For this reason, students who learn through the conventional model tend to have lower science process skills

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than students who learn to use the Discovery Learning model. The analytical results for the difference in module impact on student's critical thinking skills can be seen in Table 5.

Table 5. The Average Corrected Score of Critical Thinking Skills by the Module

Modules	Average Pre-test CTSs	Average Posttest CTSs	Difference	Average Corrected CTSs
Discovery Learning-based Multiple Representation	41.26	68.14	26.88	66.79
Conventional	40.14	57.82	17.68	57.29

The Discovery Learning-based, Multiple Representation modules received an average adjusted value of 66.79 for critical thinking skills. It was more significant than the average corrected value of 57.29 for the traditional module. It demonstrated that students enrolled in the Generative Learning-based biology module possessed superior critical thinking abilities compared to those in the conventional biology module.

It occurred as a result of the fact that the Discovery Learning-based Multiple Representation modules included a large number of tasks during the learning stages. These exercises made a concerted attempt to foster critical thinking abilities. The model-based constructivism paradigm would compel students to participate in the activity (Carey, 2011; Champine et al., 2009). Because the traditional module contains little activity, students are not engaged in knowledge construction. The typical model contributes nothing to students' knowledge construction (Masek & Yamin, 2012).

The difference in the effect of science process skills on critical thinking abilities is shown in Table 6.

Table 6. Corrected Score of student's CTSs by SSP

Science Process Skills	Average Pre-test CTSs	Average Posttest CTSs	Difference	Average Corrected CTSs
Low	20.62	42.04	21.42	41.72
High	60.17	80.91	20.74	80.56

The data in Table 6 demonstrate that strong science process skills are statistically substantially different from low scientific process skills. Students with solid science process abilities had an average adjusted value of 80.56 for critical thinking ability. It was more significant than the average corrected score for low science process skills, 41.72. It was discovered that students with strong science process skills had a greater capacity for critical thinking than those with low science process skills.

Family, school, and psychosocial factors mainly cause these differences. Family support, competitive classes, and low social self-esteem can all contribute to diversity. Students' talent, persistence, and ability in the class are represented as normal distribution. With this condition, if all students receive the same teaching model, learning materials, and study period, their learning achievement will be normally distributed. The students will be categorized into low and high science process skills. High-ability students are better able to respond and understand lessons than low-ability students. With the skills and abilities, they have, students with high science process abilities will understand the lesson better, and thus their critical thinking skills are significantly higher than students with low science process abilities.

Numerous student activities have the potential to strengthen students' cognitive processes. It can occur due to students actively developing a meaning system and comprehending a truth through their experiences and interactions with learning materials and peers (King et al., 1998; Kuhn et al., 1988; Presseisen, 2001). As a result, it prompted students to do extensive research using scientific methods. According to Piaget, each individual has an inherent curiosity and constantly seeks to comprehend their environment (Krathwohl et al., 2002).

Concerning SSP abilities, the ANCOVA test result in Table 4 indicated a significant value of .008 (< .05) for the interaction data between module and science process abilities, indicating a difference in learning module interaction with science process abilities toward critical thinking ability. As a result, it was discovered that there was an interaction between the learning module and scientific process abilities, which resulted in the development of critical thinking abilities. The lsd test was used to

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determine the association between each position of the learning module and reading motivation at a significance level of .05, as shown in Table 7.

Table 7. Interaction of Learning Module of SSP toward CTSs

Interaction	Pre-test CTSs	Posttest CTSs	Difference	Corrected CTSs	Notation
Discovery Learning*Low Science Process Skills	22.27	66.10	43.83	65.70	a
Discovery Learning*High Science Process Skills	60.74	85.92	25.18	85.12	b
Conventional*Low Science Process Skills	18.97	37.97	19.00	36.99	c
Conventional*High Science Process Skills	59.61	75.91	16.30	75.21	a

Table 7 demonstrated that students with high science process skills (HSPS) who participated in the Discovery Learning-based Multiple Representation modules performed significantly better than those with low science process skills (LSPS) and those who participated in the traditional module. As can be observed from the average adjusted score for the interaction between the Discovery Learning-based Multiple Representation modules and the HSPS, students received the highest possible score of 85.12. The results suggested that the Discovery Learning-based Multiple Representation modules were more effective than other interactions for HSPS students. The conventional module application for HSPS students used the same notation as the Discovery Learning-based Multiple Representation module application for LSPS students. The findings indicated no statistically significant difference in students' critical thinking ability between the two encounters. However, when the conventional module was presented to students, the average corrected value indicated that HSPS students possessed more extraordinary critical thinking ability than LSPS students when the Discovery Learning-based Multiple Representation modules were applied. Using a typical module with LSPS students revealed that critical thinking ability was the least developed of all the interactions.

Critical thinking is a critical capacity in the twenty-first Century that students could utilize to address difficulties in the classroom or daily life (Facione, 2011). Students were taught to use critical thinking skills to process knowledge to reach a conclusion rather than memorize it (Nuangchalerm & Thammasena, 2009). However, kids with HSPS demonstrate a greater capacity for critical thinking than kids with LSPS. Thus, students with LSPS should develop critical thinking skills through science process activities such as the Discovery Learning-based Multiple Representation modules, which included activities or activities that facilitated the development of critical thinking skills, because students' comprehension of concepts will increase as they gain experience with self-directed learning (Csikszentmihalyi, 1996; van Joolingen, 1999).

CONCLUSION

This research concludes that a module for Multiple Representation based on Discovery Learning has been developed. Multiple Representation module based on Discovery Learning is more effective than conventional module at strengthening students' critical thinking skills. The interaction of the Discovery Learning-based Multiple Representation modules has the most potent critical thinking abilities in students with strong science process skills. On the other hand, students with low science process skills who interact with Discovery Learning-based Multiple Representation modules exhibit the same level of critical thinking as students with good science process skills who interact with a conventional module. The module's application must be complemented by the encouragement of SSP abilities and enthusiasm to learn.

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