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ENHANCING CRITICAL THINKING: INTEGRATING GUIDED DISCOVERY LEARNING AND CONCEPT MAPPING (GDL-CM) IN CLIMATE CHANGE CONCEPT

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ABSTRACT

Indonesia is confronted with the challenge of climate change, which adversely impacts students by diminishing their motivation to learn and causing various health problems. Addressing climate change requires an educational approach that emphasizes critical thinking skills, enabling students to comprehend, analyze, and devise solutions for these issues. This study analyzes the influence of the GDL-CM model on students' critical thinking skills on climate change material. This research is conducted at SMAN 36 Jakarta in January-May 2024. The research method used is a quasi-experiment and Nonequivalent Pretest-Posttest Control Group design. The study sample includes 62 students, with 31 students per class selected using a simple random sampling. The normalized gain value shows that the GDL-CM effectively improves critical thinking skills. Based on hypothesis testing using an independent t-test at $\alpha = 0.05$, there is an influence of the GDL-CM learning model on students' critical thinking skills on climate change material. The influence is considered significant based on the effect size value. The results of this study imply that the GDL-CM learning model should be an alternative learning medium to develop critical thinking skills.

Keywords: climate change; concept mapping; critical thinking skills; GDL

INTRODUCTION

Indonesia confronts intricate environmental challenges, including climate change, which profoundly affects human life (Arwan et al., 2021; Amalia et al, 2024). Climate change affects education by necessitating the adaptation of curricula and school infrastructure. Students experience the direct impact of climate change, such as rising temperatures and extreme weather events, which disrupt school days and cause them to miss class (Hussaini, 2023). To address this issue, it is important to integrate climate change material into education. Climate change material is a science learning topic emphasizing students' involvement in decision-making and problem- solving regarding global warming and greenhouse gas effects from human activities (Arwan et al., 2021; Puspaningsih et al., 2021). Teachers can enhance students' understanding by relating this topic to everyday life, encouraging them to contribute to reducing the impact of climate change (Carman et al., 2021).

Students need 4C skills—critical thinking, collaboration, creativity, and communication—to solve climate change problems (Permendikbud No. 36 2018). Critical thinking skills are essential for addressing everyday challenges (Suryanda et al., 2020; Gilmanshina et al., 2021; Yulianti et al., 2022). In biology lessons, critical thinking skills help students develop analytical, inductive, and deductive abilities to solve problems (Bassham et al., 2010; Mahanal et al., 2019). Students who can think critically can find effective solutions for

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climate change mitigation and adaptation (Atabaki et al., 2015; Stevenson et al., 2017; Hakim et al., 2023). However, critical thinking skills among Indonesian students are still low. Studies show that the critical thinking skills of high school students in Batu and East Jakarta are still lacking (Zubaidah et al., 2015; Azrai et al., 2020). This is due to teaching methods that focus more on memorization and questions and less emphasis on reasoning and analysis (Azrai et al., 2020; Lestari et al., 2021). Therefore, an effort is needed to optimize students' critical thinking abilities through a learning process.

The assessment developed for critical thinking skills should preferably be in the form of open-ended tests rather than multiple-choice tests, as open-ended tests are considered more comprehensive. Examples of open-ended assessments include multiple-choice tests with written explanations, essay tests followed by critical thinking, and performance assessments (Ennis, 2011). To enhance critical thinking skills, teachers must be able to create learning experiences that train students to actively seek learning information and build cognitive structures (Patonah, 2014). This can be achieved by creating an interactive classroom environment. Students are viewed as thinkers, while teachers act as mediators, facilitators, and motivators (Janssen et al., 2014; Susanto, 2015). Therefore, critical thinking skills can be enhanced through consistent guidance and the use of appropriate teaching models (Eklof, 2005; Fuad, 2017; Noviyanti et al., 2019). The Guided Discovery Learning (GDL) model in biology has a positive impact on the development of critical thinking skills (Reynolds & Chiu, 2013; Noviyanti et al., 2019).

The use of Guided Discovery Learning (GDL) in biology education emphasizes student engagement in integrating comprehensive knowledge through teacher guidance and peer interaction (Ristanto et al., 2022). During GDL sessions, educators illustrate complex issues and pose questions to foster students' critical thinking skills in formulating problem-solving conclusions (Goleman, 2013; Amalia et al., 2019; Atiyah et al., 2020). GDL has demonstrated efficacy in stimulating curiosity and enhancing the ability to address high-level challenges (Miarsyah & Ristanto, 2019; Sartono et al., 2018). However, this instructional approach is noted for requiring thorough preparation to cultivate robust thinking skills (Moedjiono & Dimyati, 1992). To address this challenge, solutions such as Concept Mapping (CM) have been proposed (Prammudya & Subiantoro, 2022). Data obtained during GDL sessions can effectively be presented using CM (Muhali & Sukaisih, 2023).

CM enhances biology learning by requiring students to connect related concepts systematically, making learning more meaningful and improving understanding (Darmawan et al., 2018; Azrai et al., 2020). Students can utilize CM as a tool to connect information derived from identifying, evaluating, and reasoning about initial knowledge pertaining to existing issues (Daniela, 2015).

CM has proven effective in enhancing critical thinking skills in various contexts, such as improving nursing students' analytical abilities (Lee et al., 2013) and high school students' understanding of linear motion concepts (Negoro et al., 2018). The GDL model integration with CM is conducted with high school students to enhance their comprehension of immune system concepts (Kholifah et al., 2015). Implementing the GDL model alongside CM strategies in action research can improve students' metacognitive and critical thinking skills (Muhali & Sukaisih, 2023). Despite the promising results of using GDL and CM individually in various contexts, such as enhancing students' critical thinking in biology (Reynolds & Chiu, 2013; Sartono et al., 2017), there is a lack of research that combines both methods in addressing interdisciplinary topics like climate change. While GDL has been shown to promote higher-order thinking and CM has effectively improved concept understanding, their integration has not been tested in the context of global issues like climate change. This study aims to fill this gap by analyzing how the integration of GDL and CM can enhance students' critical thinking skills specifically in climate change education.

The limitation of this research is focused on examining the impact of the GDL-CM model on the critical thinking skills of tenth-grade students (X/E) specifically in the climate change material. The research will only address the biology curriculum in relation to climate change and will not explore other interdisciplinary topics or educational levels

METHODS

This research used a Nonequivalent Pretest-Posttest Control Group Design (Creswell & Creswell, 2017), as illustrated in Table 1 below. This method was utilized to investigate the influence of the treatment on the experimental class utilizing the GDL-CM model. The control group employed a Discovery Learning model.

Table 1. Nonequivalent Pretest-Posttest Control Group Design

Group	Pretest	Treatment	Posttest
Experimental Class	O1	X	O2
Control Class	O3	C	O4

Description O1: Pretest of the experimental class; O2: Posttest of the experimental class; O3: Pretest of the control class; O4: Posttest of the control class; X: Treatment in the form of applying the GDL-CM model; C: Treatment in the form of applying the control class used Discovery Learning Model.

In this study, the samples taken consisted of 2 classes, which were determined utilizing purposive sampling. Based on the homogeneity test results, the samples used were class E3 as the experimental class and class E5 as the control class, each consisting of 31 students. The instruments in this study comprised two types, namely test instruments and non-test instruments (questionnaires and observation sheets). The main instrument was used to measure students' critical thinking skills, while the observation instruments were used to assess learning performance and student responses to the learning process. The observation of the implementation of learning will be evaluated based on five categories: excellent, good, fair, poor, and very poor (Riduwan, 2015). The Test instrument was an essay test comprising 15 questions with scores ranging from 0 to 5. This test instrument was tested on 32 students. Validation results using Pearson Product Moment showed that all question items were valid. The instrument's reliability was calculated using the Alpha coefficient formula (Cronbach's Alpha). Based on the calculation results, the instrument's reliability value was 0.87, which is considered high.

The details of the critical thinking skills instrument on environmental change The critical thinking skill test is divided into five main aspects (Table 2). The first aspect, Basic Clarification (K1), includes indicators such as focusing on the question, analyzing arguments, and asking and answering clarification questions, each with one question. The second aspect, Bases for a Decision (K2), involves judging the credibility of a source, observing and judging observation reports, using existing knowledge, deducing and judging deductions, making and judging inductive inferences and arguments, and making and judging value judgments. Each of these indicators also has one question. The third aspect, Inference (K3), includes the indicators of making and judging value judgments and enumerative induction, each with one question. The fourth aspect, Advanced Clarification (K4), covers defining terms and judging definitions, and attributing and judging unstated assumptions, each with one question. Lastly, the fifth aspect, Rhetorical Strategies (K5), involves determining and communicating actions with others, each with one question.

Table 2. Instrument Grids of Critical Thinking Skill Test

Aspect	Indicator
(K1) Basic clarification	Focus on question Analyze arguments Ask and answer clarification question
(K2) Bases for a decision	Judge the credibility of a source Observe, and judge observation reports Use existing knowledge Deduce and judge deductions
(K3) Inference	Make and judge inductive inference and arguments Enumerative Induction Make and judge value judgements
(K4) Advance Clarification	Define terms and judge definition Attribute and judge unstated assumptions
(K5) Rhetorical strategies	Determining actions communicating actions with others

The prerequisite tests used the normality test with Kolmogorov-Smirnov (Table 3) and the homogeneity test with Levine Test (Table 4). Hypothesis testing utilized an independent t-test to examine differences in students' critical thinking skills scores between the GDL-CM class and the control class.

Table 3. Normality Test Result

Class		**Kolmogorov-Smirnov**		
		Sig.	**α**	**Description**
Gain Score	Pretest	0.200	0.05	Normal
	Posttest	0.075		Normal

The normality calculation results in Table 3 suggested that the significance of pretest and posttest for experimental and control classes was greater than α = 0.05. The results indicated that all data were normally distributed.

Table 4. Homogeneity Test Result

Class	**Gain Score**	**N-Gain**	**Category**
Gain Score	0.067	0.05	Homogeneous

The results of homogeneity calculation as displayed in Table 5 resulted a significance that was greater than α = 0.05. It means all data were homogeneous.

RESULTS AND DISCUSSION

The result of students' critical thinking skills regarding climate change was based on their pretest and posttest scores. A summary of the descriptive statistics is presented in Table 5. The data indicates that the implementation of the Guided Discovery Learning with Concept Mapping (GDL-CM) model has a significantly positive impact on improving students' critical thinking skills. Students in the experimental class, which utilized the GDL-CM model, demonstrated greater improvement in their learning outcomes compared to students in the control class. Additionally, the variation in results among students in the experimental class decreased, indicating that this model not only enhances the average student performance but also increases the consistency of results among students. The effect of this model's implementation is considered strong, suggesting that GDL-CM is an effective approach for developing critical thinking skills on the topic of climate change.

Table 5. Data of Students' Critical Thinking Skill Test

Data	**Experimental Class**		**Control Class**	
	Pretest	**Posttest**	**Pretest**	**Posttest**
Lowest Score	24.00	69.33	33.33	65.33
Highest Score	80.00	100,00	82.67	94.67
Mean	55.65	85.24	59.65	79.18
SD	17.44	9.10	13.90	8.37
Effect size		0.87		

The research assessed five aspects of critical thinking skills in climate change. Based on Table 6 the average pretest scores for critical thinking skills indicate that both the GDL-CM and DL classes scored highest on aspects K5 and K4, lowest on aspect K2. The average posttest scores for critical thinking skills show that both classes s cored highest on aspect K4. Both classes also had the lowest average posttest scores on aspect K2. The data suggests that the Guided Discovery Learning with Concept Mapping (GDL-CM) model significantly enhances various aspects of students' critical thinking skills. Across multiple dimensions of critical thinking, students in the GDL-CM class consistently show more substantial improvement compared to those in the Direct Learning (DL) class. The effect size, which ranges from moderate to large, indicates that the GDL-CM model not only fosters a deeper understanding of the material but also equips students with stronger analytical skills. This model appears to be particularly effective in areas that require higher levels of cognitive engagement, making it a valuable tool for cultivating critical thinking abilities.

Table 6. Average Scores for Each Aspect of Critical Thinking Skills

Aspect	GDL-CM Class		DL Class		Effect Size	Category
	Pretest	Posttest	Pretest	Posttest		
	$\bar{x}$ (±SD)	$\bar{x}$ (±SD)	$\bar{x}$ (±SD)	$\bar{x}$ (±SD)		
K1	55.70 (±15.35)	86.67 (±11.55)	60.65 (±15.72)	80.22 (±12.82)	0.52	Moderate
K2	50.75 (±26.93)	74.84 (±18.44)	55.48 (±22.20)	69.46 (±15.94)	0.53	Moderate
K3	54.35 (±23.16)	83.71 (±10.72)	57.26 (±15,54)	78.55 (±11,27)	0.46	Moderate
K4	56.99 (±13.97)	93.33 (±7.70)	60.65 (±18,57)	85.16 (±11,12)	0.85	Large
K5	63.55 (±25.37)	89.03 (±14.23)	67.74 (±27,41)	84.52 (±15.46)	0.30	Moderate

Description: Basic clarification (K1), bases for decision (K2), inference (K3), advance clarification (K4) and rhetorical strategies.

According to Figure 2, the achievement of these aspects could be identified from the differences in the normalized gain of each aspect in the GDL-CM class and control class. The GDL-CM class acquired a higher normalized gain than the control class for each critical thinking skill aspect. It was related to the mean of posttest score in the experimental class that were higher than those in the control class as indicated in Table 5. The GDL-CM class has a large effect on aspect K4 based on the effect size calculated from the posttest scores.

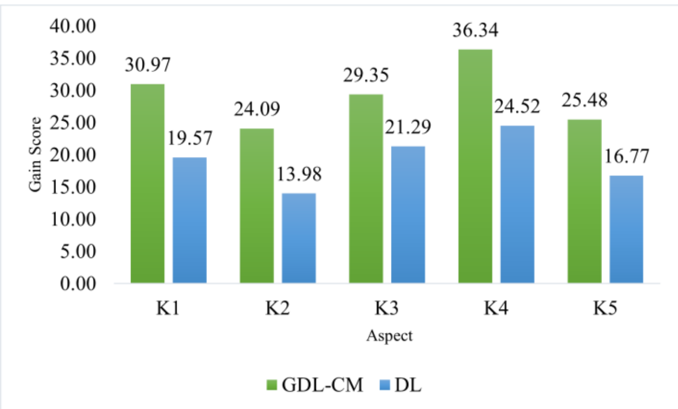

Figure 2. Achievement of Critical Thinking Skill Aspects in Experimental and Control Classes

In Figure 2, the highest improvement is found in aspect K4 in both GDL-CM and DL classes. Meanwhile, the lowest improvement is observed in aspect K2 in both GDL-CM and DL classes. Figures 3 and 4 illustrate student response samples in aspect K4 showing the highest improvement.

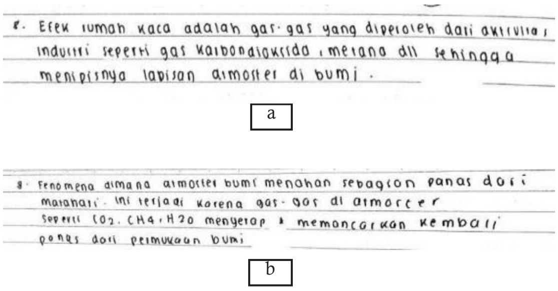

Figure 3. (a) Sample Responses of Students' Pretest on Aspect K4 of Defining Definitions Indicator and (b) Sample Responses of Students' Posttest on Aspect K4 of Defining Definitions Indicator. In this indicator, students are asked to define the greenhouse effect based on the statement given. The figure 3 explains that definition of greenhouse effect is the phenomenon where the Earth's atmosphere retains some of the heat from the sun to occur because gases in the atmosphere such as CO2, CH4, and H2O absorb and re-radiate heat from the Earth's surface

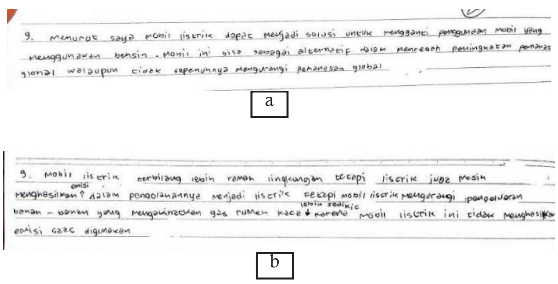

Figure 4. (a) Sample Responses of Students' Pretest on Aspect K4 Indicator Attribute and judge unstated assumptions (b) Sample Responses of Students' Posttest on Aspect K4 Indicator Attribute and judge unstated assumptions. In this indicator, students are asked to consider the assumption that uses an electric car which is Eco-friendly or not based on the statements given. The figure 4 explains the assumptions of electric cars; electric cars are considered more environmentally friendly but they still produce emissions during the process of generating electricity. However, electric cars can reduce the amount of greenhouse gases compared to gasoline-powered cars

The Normalized gain test was performed to determine the differences between the pretest and posttest in both experimental and control classes, as well as to assess the effectiveness of the learning model. The results of the Normalized Gain test are presented in Table 6. The gain scores and normalized gain calculations in the experimental class were higher than those in the control class. In terms of effectiveness, the experimental class using the GDL- CM learning model was somewhat more effective than the control class using DL.

Table 7. Normalized Gain Test

Class	Gain Score	N-Gain	Category
GDL-CM	29.59	0.67	Medium
DL	19.52	0.48	Medium

The hypothesis testing used independent t- test of gain score to find out the influence of GDL- CM model on critical thinking skills in climate change content. The calculation of independent t-test used SPSS version 25. The result of gain score t-test calculation suggested that ρ was less than α with significance value of 0.001 or less than 0.05; thus, H0 was rejected. It means there is a significant impact of the GDL-CM learning model on students' critical thinking skills in climate change content. The results are presented in Table 7.

Table 8. Independent t-test of Critical Thinking Skills Gain score

	T	α	Sig. (2-tailed)
Gain score	3.43	0.05	0.001

This research also included observing the implementation of the learning process. Observations were conducted by observers using an observation sheet designed based on the lesson plan's syntax. The results are presented in Table 8.

Table 9 . Percentage of Learning Implementation

Subject	Class	Average Score (%)	Description
Teacher	GDL-CM	95.00	Excellent
	DL	92.50	Excellent
Students	GDL-CM	97.50	Excellent
	DL	95.00	Excellent

This study aims to investigate the effect of the GDL-CM learning model on students' critical thinking skills regarding climate change. Based on the hypothesis using t-test (Table 11), it was found that the GDL-CM learning model significantly influences students' critical thinking skills regarding climate change. This research aligns with the findings of Muhali et al. (2023), which suggest that biology learning using the GDL model significantly aids students in enhancing critical thinking skills.

According to Table 3, the average pretest scores of the experimental and control groups were nearly identical. After the intervention, the average posttest scores for critical thinking skills in the experimental group were higher than those in the control group. This indicates improvement in the experimental group. This improvement can be observed in Table 5, which shows higher gain scores and normalize gain values for the GDL-CM group. These results are in line with research that the GDL model effective for increasing students' critical thinking skills (Yuliani & Saragih, 2015; Fadillah et al., 2018; Noer, 2018; Batubara, 2019; Banila et al., 2020).

The improvement in students' critical thinking skills in both the experimental and control groups can be analyzed based on the syntax of the GDL-CM model, which comprises five stages: stimulation, problem statement, guiding process (data collection and data processing), verification, and generalization (Bruner, 1961). CM is employed at each stage, adapted from Ristanto et al. (2022). The discovery learning approach differs primarily in the data collection and processing stage, where there is no teacher-guided process involved in the learning process, unlike in the control group using discovery learning without CM in every stage. The use of CM in each learning syntax assists students in enhancing critical thinking skills; CM serves as a means for students to connect new information with prior knowledge, thereby facilitating meaningful learning experiences (Daniela et al., 2015).

The enhancement of students' critical thinking skills in both experimental and control groups can be assessed using the GDL-CM model, which includes five stages: stimulation, problem statement, guiding process (data collection and processing), verification, and generalization (Bruner, 1961). Concept Mapping (CM) is integrated at each stage, adapted from Ristanto et al. (2022). The discovery learning model differs only in the data collection and processing stages, where no teacher guidance is provided, and CM is not used. CM helps students connect new information to prior knowledge, enhance critical thinking and foster meaningful learning (Daniela et al., 2015).

The learning activity starts with the stimulation stage, where students are given a stimulus to activate their prior knowledge about the topic to be studied (Kartini et al., 2021). During this stage, the teacher presents something that creates confusion, prompting students' motivation to explore further. Subsequently, students are asked introductory questions related to climate change (Habib et al., 2021). In the experimental class, students receive a stimulus in the form of CM that discusses climate change, whereas in the control class, the stimulus consists only of images of climate change phenomena. Using CM as a stimulus aids students in comprehending the teacher's questions, thus motivating them to investigate the topic more deeply (Cañas et al., 2015).

The second stage is the problem statement. During this stage, students are provided with the opportunity to identify issues pertinent to the lesson material and subsequently select and formulate them into hypotheses (Iswati & Purwati, 2022). Students are encouraged to pose questions, which will then be used to formulate the problems to be addressed (Rini, 2020). In the experimental class, students are given additional questions related to climate change and are guided in identifying other issues using the previously displayed Concept Mapping (CM). Conversely, in the control class, students are asked to pose questions without any teacher guidance in identifying the problems.

Teacher guidance helps students identify problems, allowing them to focus on the topic (Rini et al., 2021). Thus, the problem statement stage simplifies the creation of CM and the completion of worksheets in later steps, where students must identify and solve problems.

Next is the guiding process involving data collection and processing. In the experimental class, students work in groups to solve climate change- related issues using worksheets and information from CM and other sources. In the second session, they create CM in groups and process data to formulate answers. Discussions help finalize responses and enhance understanding (Murphy et al., 2018). Creating CM enhances students' critical thinking skills, as teachers can assess how well students represent concept relationships (Bilik et al., 2020). In the guiding process stage, teachers assist students in gathering information and problem-solving, while in the control class, students work independently on their worksheets.

The fourth stage is verification stage, students present their group discussions to the class and respond to feedback from other groups. They use provided sources to complete worksheets and create CM, but also gather additional materials to support evidence and facts about climate change issues. This step promotes critical thinking by encouraging detailed explanations (Chich, 2016; Noviyanti et al., 2019), helping students articulate their own arguments and respond to diverse viewpoints to reach informed conclusions. In the control class, this stage also occurs, but students only present their worksheets without using CM (Keiler, 2018).

The final stage is generalization or drawing conclusions, where students and teachers collectively reach conclusions. Formulating conclusions is essential in the learning process, enabling students to find answers after going through the thinking process of gathering data. Drawing conclusions is a crucial component of critical thinking, where students analyze and consider the data, information, and sources used (Marwah et al., 2022; Hillary et al., 2023). Conclusions lead students to accurate knowledge. In the experimental class, students use CM to draw conclusions about climate change issues provided, together with the teacher. The characteristics of CM help students develop strong critical thinking skills (Lee, et al., 2013; Rachmantika & Wardono, 2019). CM includes concepts, propositions about relationships between them, and is structured hierarchically from general to specific concepts. It features cross-links showing connections between concepts and specific examples to clarify meanings (Novak, 2006; Zubaidah et al., 2016).

The average scores for each aspect of critical thinking skills were analyzed in this study. The critical thinking aspects used in this research were developed by Ennis (2016). Based on Table 4, climate change topics showed the highest average scores in advance clarification aspect. According to Figure 2, the highest improvement also occurred in advance clarification aspect based on gain score values and effect size value. This demonstrates that students are proficient in identifying terms and adept at evaluating definitions and assumptions. The advance clarification stage is practiced during the verification stage, students in the experimental class effectively utilize CM to expound on evidence, facilitated by its visual structure that enables systematic organization and connectivity of information (Al-Shaer, 2014).

Based on Figures 3 and 4, students demonstrate an understanding of the greenhouse effect and can critically assess assumptions related to emissions from electric cars. Their thoughtful consideration of these assumptions significantly impacts how they evaluate information and construct detailed arguments, substantiating their points (Ramadhani et al., 2021). The improvement in this aspect aligns with previous research, indicating that biology learning using problems relevant to everyday life is easier to address compared to other aspects (Ristanto et al., 2021). This enriches biology teaching by making the learning process more engaging and providing students with opportunities to enhance their skills in evaluating information and constructing detailed arguments (Kirby et al, 2019).

In the experimental class, all aspects of critical thinking skills showed higher normalized gains compared to the control class. This was due to the use of the GDL-CM learning model. In the first stage of GDL-CM, students are given problems related to the material and are expected to solve them using their existing knowledge. This learning step enhances rhetorical strategy aspects (Roohani & Hashemian, 2017).

During GDL-CM instruction, students learn to formulate problems and hypotheses, enhancing their ability to provide simple explanations. The GDL model steps for problem formulation require analysis, thereby developing critical thinking skills (Reynolds & Chiu, 2013). GDL-CM also involves students in seeking supporting facts and evidence, thereby enhancing basic clarification aspect (Fuad et al., 2017). In the GDL-CM class, the inference aspect is higher due to students conducting reviews during the Generalization stage and evaluating evidence and facts obtained with CM's assistance to aid in drawing conclusions from existing problems. Intensive guidance in the GDL-CM class provides clear directions for students to correctly strategize problem-solving. Teacher guidance accelerates fact- finding compared to DL classes, where students lack teacher guidance, direction, or instructions, leading to unguided learning experiences (Onikarini et al., 2019).

The process of implementing learning in teachers and students was also analyzed in this study through observation sheets. The result can be seen in Table 9. Students in the experimental group showed higher success rates in learning activities compared to the control group. These findings suggest favorable outcomes for both groups according to predefined criteria (Riduwan, 2015), indicating unbiased implementation of teaching strategies across both classes (Istiani et al., 2018).

The implementation of the GDL-CM model has been proven to significantly influence students' critical thinking skills in climate change topics at every stage and aspect. The effectiveness of the GDL- CM model's impact is observed through the effect size value in Table 11, which is 0.87, indicating a high category of effectiveness. The impact of the GDL-CM learning model is attributed to its ability to help students utilize information and build their understanding, thereby making content comprehension more meaningful for them (Handoko et al, 2016; Bahtiar & Dukomalamo, 2019). Consequently, it is expected that after learning, students can implement the concepts they have learned in their daily lives, such as reducing the use of personal vehicle, limiting activities contributing to greenhouse gas emissions, and taking other steps that support positive climate change efforts.

CONCLUSION

The GDL-CM learning model significantly enhances students' critical thinking skills in climate change education compared to the DL model, as evidenced by the effect size and normalized gain results. This innovation is particularly effective in advancing students' understanding, with notable improvement in the advance clarification aspect. The GDL-CM model is recommended for enhancing critical thinking in climate change education, offering a structured approach that combines teacher guidance and active student participation. Teachers must grasp GDL-CM syntax thoroughly before teaching. Future research should encourage students to take a more active role in the learning process to optimize CM creation. Furthermore, this study can serve as a reference for researchers exploring the positive potential of using the GDL-CM model in various biology topics or through other 21st century skill aspects.

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