

Can STEM Learning Supported by Dynamic Mathematics Software (DMS) Enhance Students' Complex Problem Solving in Climate Change?

Lillian Dhian Nafiatul Azhar¹, Megita Dwi Pamungkas^{*2}, Dita Aldila Krisma³

^{1,2,3}Mathematics Education, Universitas Tidar, Indonesia

Email Address: megitadwip@untidar.ac.id

*Corresponding author

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Abstract:

The development of students' Complex Problem Solving (CPS) skills remains constrained by mathematics instruction that is primarily procedural and insufficiently connected to real-world global issues, particularly climate change. To address this limitation, the present study investigates whether STEM learning supported by Dynamic Mathematics Software (DMS) can improve senior high school students' CPS abilities within climate change contexts. A quasi-experimental, non-equivalent pretest-posttest control group design was implemented with 69 eleventh-grade students. The experimental group participated in STEM learning integrated with DMS, while the control group received direct instruction on the same climate change context. Data were analyzed using descriptive statistics, Wilcoxon signed-rank tests, paired-sample t-tests, N-Gain, and Cohen's D. Results showed that the experimental group achieved a high N-gain score (0.79), whereas the control group attained a low gain (0.29). The magnitude of this increase is also reflected in the effect size Cohen's d values, 5.893 in the experimental class and 2.438 in the control class. These findings suggest that STEM learning supported by Dynamic Mathematics Software constitutes an effective pedagogical strategy for advancing students' complex problem-solving skills and strengthening mathematics education.

Keywords: Climate Change; Complex Problem Solving; Dynamic Mathematics Software (DMS); Problem-Based Learning; STEM Education.

Introduction

In an era of global disruption and increasing complexity, students are required not only to master subject knowledge but also to develop higher-order thinking skills that enable them to analyze, adapt, and act in uncertain situations. One essential skill is Complex Problem Solving (CPS), which involves identifying problem structures and relevant variables, modeling relationships, and evaluating solutions through iterative and reflective processes. The World Economic Forum consistently ranks CPS among the top ten essential 21st-century skills (Masterson, 2022), underscoring its importance in education, work, and social life (Molnár et al., 2022). In secondary education, CPS



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serves as a crucial bridge between academic knowledge and real-world competencies needed to address global challenges.

However, the development of students' CPS skills remains limited. Many students struggle to transfer foundational knowledge into CPS frameworks, particularly when confronted with complex, non-routine problems (Nicolay et al., 2021; Pamungkas et al., 2023). CPS has even impacted major tests like PISA (Programme for International Student Assessment), but challenge is reflected in PISA 2022 results, which showed that only 18% of Indonesian students achieved at least Level 2 mathematical proficiency, the minimum level required to interpret and apply mathematics in real-life contexts. Although mathematics education should foster authentic, interdisciplinary problem solving, classroom practices in Indonesia are still dominated by procedural tasks and recall-based assessments, limiting students' opportunities to model phenomena, analyze data, and make evidence-based decisions (Ulia et al., 2024). These findings underscore the importance of integrating real-life contexts into mathematics instruction in order to develop CPS in a more meaningful way.

One context that is relevant to addressing the challenge of low CPS is the climate change. Climate change provides a highly relevant context for fostering CPS, as it is a complex, global, and multidimensional issue requiring interdisciplinary understanding and data-driven reasoning (Bates et al., 2022). UNESCO and the IPCC emphasize the integration of climate change education to prepare environmentally literate and action-oriented citizens. However, in Indonesia, mathematics instruction remains largely focused on mechanistic and procedural aspects and is often detached from real-life contexts (Masjudin, 2024). This condition contributes to a gap between students' conceptual understanding and their ability to apply mathematical knowledge when addressing global challenges.

Despite this considerable potential, it has not yet been fully realized in the Indonesian context. Preliminary observational data indicate that only 43.38% of senior high school students were able to solve data-based complex problems, and only 22% were able to connect mathematical concepts to climate change issues. The majority of students remained focused on procedural-type problems. An analysis of students' responses reveals that CPS skills were not yet evident. Preliminary observations indicated students' limited CPS performance, particularly in orientation, conceptualization, and strategy formulation.

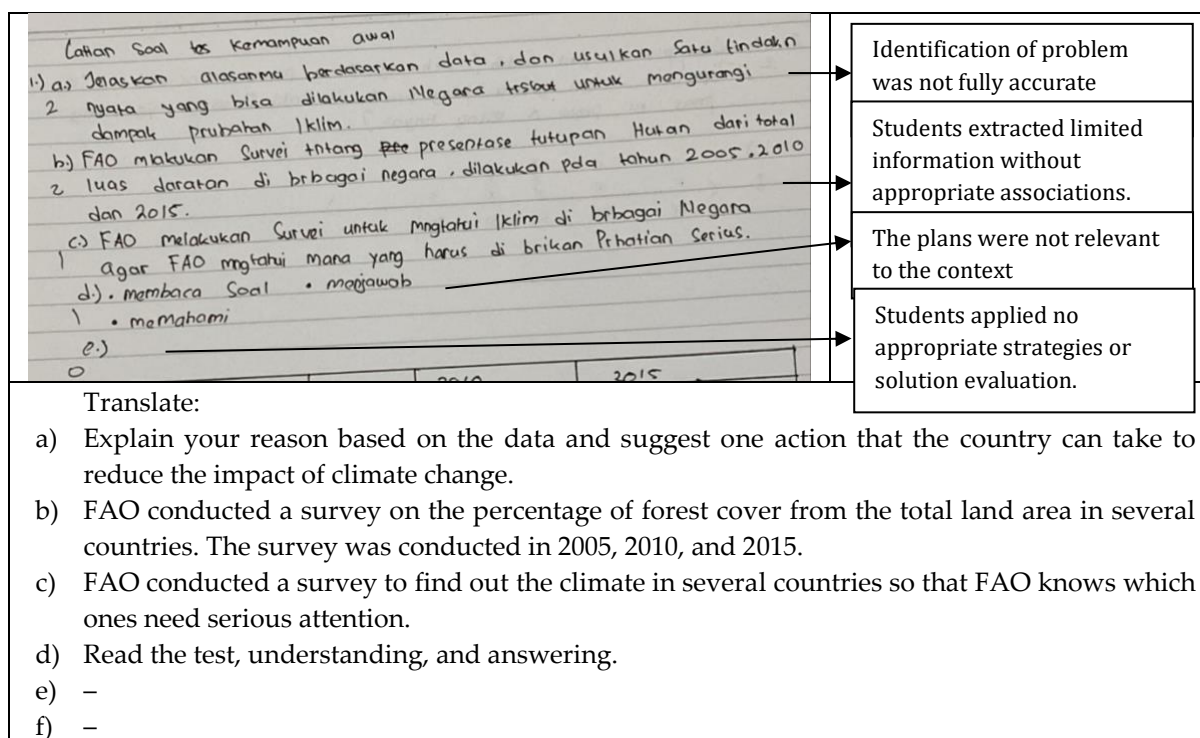


Figure 1. Answers Sheet of students with low CPS

This problem is further corroborated by interview data involving one senior high school mathematics teacher and three students revealed that climate change had never been used as a learning context, while additional challenges included difficulty interpreting graphs and visual data, as well as external disruptions such as extreme weather conditions. These gaps are compounded by the minimal and unsystematic use of Dynamic Mathematics Software (DMS) in classrooms, despite evidence that such tools support interactive visualization and conceptual understanding (Rizki & Suprpto, 2024). The observation also showed that the learning process only focuses on procedural learning, with a lack of exploration and limited media to support learning. This is in line with the finding that climate change is a “super-wicked” problem involving scientific, social, economic, and political dimensions, making it difficult to address through traditional disciplinary approaches (Cross & Congreve, 2021).

One effective strategy to address low CPS skills and awareness of climate change is to apply a STEM approach to learning, integrating DMS as a ‘technology’ element to support learning. STEM approach has gained global recognition as an effective framework for fostering CPS through interdisciplinary and real-world problem solving (AlAli, 2024; Chen et al., 2025). This learning method not only encourages student engagement in the learning process, but also allows students to explore concepts through DMS visualize and manipulate climate-related data, thereby building students' experience of dynamic and meaningful learning (Chechan et al., 2025; Szilágyi et al., 2024). Moreover, studies that explicitly combine a STEM approach, DMS, and climate change contexts remain scarce. This gap is particularly concerning given that Indonesia is among the countries most vulnerable to the impacts of climate

change and therefore bears a significant responsibility to prepare future generations capable of systemic thinking and solution-oriented action (Climate Risk Country Profile, 2021; Shirvell, 2023). This situation highlights the gap between the potential of STEM approach supported by DMS as a dynamic learning and its actual implementation in the classroom.

Therefore, an approach is needed that can integrate the overall STEM approach with the help of DMS and is oriented towards CPS skills that remain in line with the applied curriculum. The context of climate change is used as an adaptation to climate change in Indonesia. The novelty of this research lies in the integration of STEM learning with the use of DMS to support the development of students' CPS skills in the context of climate change in mathematics learning. This study also contributes to the field of mathematics education by providing empirical evidence on how technology-supported STEM learning can improve CPS skills while connecting mathematical modeling with global challenges. To achieve this goal, this study aims to examine the effectiveness of a of a STEM-based approach supported by DMS in enhancing senior high school students' CPS skills within a climate change context.

Literature Review

STEM Approach in Mathematics Education

The STEM (Science, Technology, Engineering, and Mathematics) approach is an interdisciplinary framework that integrates multiple disciplines to address real-world problems (Fajrina et al., 2020). In mathematics education, STEM supports not only conceptual understanding but also the application of mathematical ideas through modeling and solution-oriented processes (Veraldo et al., 2024). Effective STEM implementation requires instructional models that actively engage students in authentic problem solving and collaboration. Problem-Based Learning (PBL) aligns well with these requirements by using contextual problems as the starting point of learning, thereby promoting investigation, complex thinking, and solution development. Prior studies have shown that STEM–PBL integration effectively fosters 21st-century skills, particularly complex problem solving and critical thinking (Dorimana et al., 2022; Pamungkas et al., 2024; Suparman et al., 2021). Therefore, PBL was selected as the instructional model in this study to support STEM implementation and to facilitate the development of students' CPS skills. According to Arends, the PBL syntax consists of five stages, as shown in the following table.

Table 1. Syntax of PBL with STEM Approach

Syntax PBL	STEM	Learning Activities
Student orientation on the problem	Science	Students are actively involved in phenomena of microgreens and the factors that influence plant growth.
Organize student to learn	Engineering	Students identify variables, their relations, and design procedures for conducting microgreen planting experiments and linear regression.
Guiding individual or group	Technology	Students use DMS to explore and monitoring data, and manipulate graphs dynamically.

Syntax PBL	STEM	Learning Activities
Develop and present the group	Mathematics	Students build linear regression models, calculate model parameters, and form regression equations.
Analyze and evaluate the problem solving process	STEM	Students interpret the results of calculations and make predictions about factors affecting plant growth based on linear regression results

Complex Problem Solving (CPS) in Learning

Complex Problem Solving (CPS) refers to the ability to address dynamic and ill-structured problems through iterative and strategic processes (Nicolay et al., 2023). CPS encompasses both cognitive components, such as problem identification and data analysis, and metacognitive processes, including planning, monitoring, and evaluation (Smith et al., 2022; Wahdaniyah et al., 2023). In secondary education, CPS is essential for engaging with complex global issues such as climate change, which require interdisciplinary reasoning and evidence-based decision making. Reflecting its importance, CPS has been emphasized in international assessments such as PISA and identified by the World Economic Forum as a key future workforce skill. According to (Funke, 2010) the process of complex problem solving consists of two main phases:

- 1) *Knowledge Acquisition*, which refers to the phase in which the problem solver applies prior knowledge to make a series of dynamic decisions while continuously monitoring the consequences of those decisions in order to systematically address the problem at hand.
- 2) *Knowledge Application*, which refers to the phase in which the problem solver systematically generates information (by seeking informative data), integrates this information into a coherent situational model (by formulating appropriate hypotheses), and selectively focuses on the most relevant aspects of the problem.

CPS skills are closely associated with students' learning outcomes, particularly in mathematics learning, which requires the application of complex techniques to solve problems.

The Role of Dynamic Mathematics Software (DMS) in Mathematics Education

Dynamic Mathematics Software (DMS) refers to computer-based technologies in mathematics education that are commonly classified as Computer Algebra Systems (CAS) and Dynamic Geometry Software (DGS) (Hohenwarter & Fuchs, 2004). DMS plays a crucial role in supporting the conceptualization and application of dynamic mathematics and is widely used as an instructional tool across educational levels (Phooddee et al., 2024). Empirical evidence indicates that the use of DMS facilitates multimodal representations and enhances students' conceptual understanding (Weinhandl et al., 2024). Within a STEM-based approach, DMS strengthens the integration of technology and supports students in modeling and simulating problem solutions in real time, thereby fostering higher-order thinking skills and STEM

competencies through exploratory, simulation-based, and reflective learning activities (Kramarenko et al., 2020; Lan et al., 2021; Md-Ali & Kim, 2018; Yohannes & Chen, 2023).

Mathematics Education in the Context of Climate Change

Climate change arises from complex interactions among solar radiation, thermal processes, and internal climate system variability (Rahmstorf & Schellnhuber, 2018). As the world’s largest archipelagic country with over 275 million people, Indonesia is highly vulnerable to climate change impacts while also ranking among the top global greenhouse gas emitters (Boehm et al., 2023). Among the sectors most affected is food security, which encompasses availability, access, utilization, and stability (El Bilali et al., 2020). Increasing climate-related disasters pose serious risks to Indonesia’s food systems, highlighting the urgent need for adaptive and sustainable solutions (Malau et al., 2021).

One promising strategy is microgreen cultivation, which offers high nutritional value, production efficiency, and adaptability to controlled environments, although challenges related to sustainability and productivity remain (Abaajeh et al., 2023; Barańska et al., 2025; Kainikkara et al., 2025; Kondratenko et al., 2022; Seth et al., 2025). From an educational perspective, mathematical arguments are frequently misused in climate change denial, underscoring the importance of equipping students with critical mathematical literacy to enable informed decision-making and meaningful participation in data-driven public discourse (Barwell & Hauge, 2021). A STEM approach is particularly relevant, as it enables the integration of mathematical modeling, data interpretation, and prediction within meaningful climate change contexts (Siller et al., 2024). Through climate change–contextualized mathematics learning, students develop not only core mathematical competencies such as proportional reasoning and regression analysis but also the capacity to engage critically with real-world environmental challenges, supporting informed decision-making and long-term sustainability.

Research Methods

Research Design

This study employed a quasi-experimental method using a non-equivalent pretest–posttest control group design (Ary et al., 2009). In brief, the research design can be described as follows:

Table 2. Research Design

	Group	Pretest	Independent Variable	Posttest
(R)	E	Y_1	X	Y_2
(R)	C	Y_1	–	Y_2

Notes: *E* denotes the experimental group, *C* denotes the control group, and *X* represents the STEM-based approach supported by DMS.

Table 3. Research Treatments

Aspect	STEM-based approach supported by DMS	Direct Instruction
Time	<i>Pretest: 2 × 40 minutes</i> <i>Lesson: 6 × 40 minutes</i> <i>Posttest: 2 × 40 minutes</i>	
Learning Steps	a) The teacher explains the objective and learning process b) Learning process: using the Problem-Based Learning (PBL) syntax to implement a STEM-based approach supported by DMS (Desmos) as learning activities c) Evaluation	a) The teacher explains the objective and learning process b) Learning process: using the Direct Instruction syntax as learning activities c) Evaluation
Context	Microgreens as Food Security in the Context of Climate Change	
Material	Linear Regression Equation	
Student Activities	Students conducted a microgreen growth experiment to investigate factors influencing plant growth in the context of climate change. They planning to collected and organized experimental data and analyzed the relationship between variables to identify patterns in the data. Using Desmos Graphing Calculator, students explore about scatter plots and determined a linear regression equation. Finally, they interpreted the regression results and discussed possible factors affecting microgreen growth based on their experimental findings.	Students learned the concept of simple linear regression using data related to microgreen growth through teacher explanation and worked examples. The teacher demonstrated the procedures for analyzing bivariate data and determining the linear regression equation. Students then completed structured, guided, and independent exercises to practice calculating and interpreting the linear regression equation before completing the learning tasks.

Participants or Data Sources

The sample consisted of 69 Grade 11 students from SMAN 5 Magelang, selected through cluster random sampling. The experimental group (Class XI F-3, $n = 34$) received STEM-based instruction supported by DMS, while the control group (Class XI F-4, $n = 35$) was taught using direct instruction. Both groups were taught in a climate change context over four instructional sessions.

Research Instruments

The instruments used in this study consisted of observation sheets, interview protocols, validation sheets, and a pretest–posttest essay test. The CPS test was designed to assess students’ abilities across two aspect by Funke (2010)—*Knowledge Acquisition* and *Knowledge Application*—with indicators adapted from (Pamungkas et al., 2024) as presented in Table 3.

Table 4. Indicators of CPS


Aspects	Indicators	Sub Indicator(s)
<i>Knowledge Acquisition</i>	<i>Orientation</i>	1. Identifying questions within the problem.
	<i>Conceptualization</i>	1. Identifying information available in the problem. 2. Connecting the pieces of information obtained.

Can STEM Learning Supported by Dynamic Mathematics....

Aspects	Indicators	Sub Indicator(s)
	<i>Developing algorithmic design</i>	1. Developing a plan to solve the problem. 2. Formulating the necessary steps required to solve the problem.
<i>Knowledge Application</i>	<i>Develop a strategy to solve</i>	1. Applying methods or strategies used to solve the problem.

The essay test comprised three items in the pretest and four items in the posttest. One item from both the pretest and posttest measures two indicators, namely Developing Algorithmic Design-Knowledge Acquisition and Develop a Strategy to Solve-Knowledge Application, which focus on the cause-and-effect relationship of variables and also predictions from dynamic data. While each other items measures all indicators and aspects of CPS, such as identifying problems, determining variables, explaining the relationship between variables, developing plans and steps for resolution, performing regression analysis, and interpreting the results of calculations. The addition of one question to the posttest aims to assess CPS development more comprehensively because it explicitly links linear regression equation predictions to the context of climate change. Instrument validation involved six validators, including five experts in mathematics education and one senior high school mathematics teacher. Content validity was evaluated using Aiken's *V* index (Retnawati, 2016). Fielding coefficients of 0.81 for both the pretest and posttest, indicating high content validity. Validator feedback was used to refine item wording and instructions (Table 4).

Table 5. Results of Instrument Validation Revisions

Instrument Test Before Revision	Instrument Test After Revision
Corrections to wording in the test identification and instructions	
Mata Pelajaran : Matematika Materi : Statistika Bivariat (Regresi Linear) Kelas/Semester : XI/2 Alokasi Waktu : 45 menit Identitas Siswa: Nama : Kelas/Rombel : No. Absen : PETUNJUK 1. Berdoalah sebelum dan setelah mengerjakan soal. 2. Waktu pengerjaan soal 80 menit. 3. Inilah identitas Anda pada lembar jawab yang telah disediakan. 4. Bacalah soal dengan cermat sebelum mengerjakan. 5. Kerjakan soal yang dianggap mudah terlebih dahulu. 6. Gunakan bolpoin berwarna hitam. 7. Kerjakan soal secara mandiri. 8. Periksa kembali jawaban anda sebelum dikumpulkan.	Mata Pelajaran : Matematika Materi : Statistika Bivariat (Regresi Linear Sederhana) Kelas/Semester : XI/2 Alokasi Waktu : 80 menit PETUNJUK 1. Berdoalah sebelum dan setelah mengerjakan soal! 2. Waktu pengerjaan soal 80 menit. 3. Tulis identitas Anda pada lembar jawab yang telah disediakan! 4. Bacalah soal dengan cermat sebelum mengerjakan! 5. Kerjakan soal yang dianggap mudah terlebih dahulu! 6. Gunakan bolpoin berwarna hitam! 7. Kerjakan soal secara mandiri! 8. Periksa kembali jawaban anda sebelum dikumpulkan!
Revision of the imperative sentence in Item 1	
a. Tuliskan pertanyaan penelitian yang sesuai dengan data di atas.	a. Tuliskan hal yang ditanyakan dari soal tersebut.
Provide instructions for Item 3	
3. Akses Desmos: https://student.amplify.com/join/#/TWTX8X?lang=id	3. Petunjuk Akses Soal: 1) Buka tautan berikut: https://student.amplify.com/join/ERJVC7?lang=id atau pindai QR Code berikut ini.  2) Setelah halaman terbuka, masukkan identitas dirimu. 3) Kerjakan aktivitas yang ada pada halaman berikut sesuai petunjuk yang ada. 4) Klik tombol simpan.

Construct validity was examined to determine the alignment between the test results and the underlying theoretical framework (Budiyono, 2015) Construct validity was assessed using the Pearson Product–Moment correlation at a 5% significance level,

with items considered valid when $r_{cal} > r_{tab}$ (Lusiana et al., 2024) and the results indicated that all pretest and posttest items met the validity criteria. Reliability analysis using Cronbach's alpha showed coefficients of 0.59 for the pretest and 0.51 for the posttest, which fall into the moderate reliability category according to Guilford's criteria (Sundayana, 2019). This reliability value is influenced by several factors, including the relatively small number of questions and the characteristics of the essay questions, which allow for reasoning processes involving a variety of strategies and arguments for solving problems, resulting in a moderate level of internal consistency for the instrument. Item analysis indicated that most test items had moderate difficulty levels ($P \geq 0.31$) while 2 items were classified as difficult (Arikunto, 2021). All items demonstrated adequate discriminating power ($D \geq 0.20$), indicating their effectiveness in distinguishing between students with high and low CPS abilities (Fitriani, 2021). Based on these analyses, all items were deemed suitable for measuring students' CPS skills.

Table 6. Analysis of Pretest and Posttest Instruments

Test	Item	Content Validity		Construct Validity		Reliability	Difficulty Index (P)		Discrimination Index (D)		Decision
		Aiken's V	Category	r_{cal}	r_{tab}		P	Category	D	Category	
Pretest	1	0.807	High validity	0,7550	0.2913	0.59	0.56	Moderate	0.34	Adequate	Used
	2			0,6910			0.30	Difficult	0.47	Good	Used
	3			0,7467			0.53	Moderate	0.37	Adequate	Used
Posttest	1	0.809	High validity	0,6278	0.2913	0.51	0.44	Moderate	0.20	Adequate	Used
	2			0,6338			0.49	Moderate	0.44	Good	Used
	3			0,5419			0.11	Difficult	0.22	Adequate	Used
	4			0,7057			0.57	Moderate	0.35	Adequate	Used

Data were collected through classroom observations, interviews, validation questionnaires, and CPS test results. Interviews were conducted during the preliminary analysis phase to identify students' learning needs, observations were carried out during instructional implementation, and CPS tests were administered to both groups before and after the intervention.

Data Analysis Techniques

Data were analyzed using descriptive and inferential statistics. Descriptive statistics summarized students' CPS abilities through the mean, minimum and maximum scores, and standard deviation. Inferential analyses were conducted using SPSS to examine differences in CPS abilities between the STEM-based approach supported by DMS and direct instruction groups at a 95% confidence level. Learning effectiveness was evaluated using the normalized gain (N-gain) based on pretest and posttest scores, with gain levels categorized as high ($g \geq 0.7$), moderate ($0.3 \leq g < 0.7$), and low ($g < 0.3$) (Hake, 1998). Cohen's D results were used to strengthen this study.

Results and Discussions

Result

Pretest scores of CPS were collected prior to the intervention in both groups. Descriptive analysis indicated that students' initial CPS abilities were relatively low in both classes, with a mean pretest score of 18.55 (SD = 5.20) in the experimental group and 21.09 (SD = 6.07) in the control group. A summary of the pretest results is presented in Table 6.

Table 7. Pretest Results of Pretest CPS Ability

Group	<i>n</i>	X_{max}	X_{min}	Average	Std. Deviation
Experiment	34	30.21	9.36	18.55	5.20
Control	35	37.02	8.94	21.09	6.07

Prior to analyzing the pretest results of students' Complex Problem Solving (CPS) ability, prerequisite assumption tests were conducted, including normality and homogeneity tests. The Shapiro–Wilk normality test was employed because the sample size was fewer than 50 students (Kurniawan et al., 2026).

Table 8. Summary of Pretest CPS Results

Group	Shapiro-Wilk			Levene's Test of Homogeneity of Variances		independent sample t-test		Decision
	Statistic	df	Sig.	Statistic	Sig.	t-Test	Sig.	
Experiment	0.976	34	0.640	0.632	0.429	1.870	0.066	H_0 accepted
Control	0.982	34	0.846					

Normality testing (Table 7) using Shapiro-Wilk showed that that the data had a sig. value of 0.640 for experiment and 0.840 for control groups ($p > 0.05$), indicating that the data were normally distributed. In addition, homogeneous using Levene's test showed sig. 0.429 ($p > 0.05$) indicating that the variances between the groups were homogeneous. An independent samples *t*-test revealed no significant difference between the two groups' initial CPS abilities ($p = 0.066 > 0.05$), indicating that both groups were statistically equivalent prior to the intervention.

Hypothesis 1: Improvement of Students' CPS Ability in the Experimental Group

Students' CPS improvement in the experimental group was examined by comparing pretest and posttest scores. The Shapiro–Wilk test showed that pretest scores were normally distributed ($p > 0.05$), whereas posttest scores were not ($p < 0.05$); therefore, the Wilcoxon signed-rank test was applied (Thukral et al., 2023).

Table 9. Normality Test Results of Experimental Group

Class	Shapiro-Wilk			Decision
	Statistic	df	Sig.	
Experiment	Pretest	0.976	34	H_0 accepted
	Posttest	0.818	34	H_0 rejected

The results revealed a statistically significant increase in CPS performance, with all students showing positive gains ($Z = -5.086, p < 0.001$). Accordingly, the null

hypothesis (H_0) was rejected, indicating that the STEM-based approach supported by DMS significantly improved students' CPS abilities in the experimental group. The results are presented in the following table.

Table 10. Wilcoxon Signed-Rank Test

		Ranks			Test Statistics ^a		Decision
		N	Mean Rank	Sum of Ranks	Z	Asymp. Sig. (2-tailed)	
Pretest- Posttest	Negative Ranks	0	0.00	0.00	-5.086 ^b	< 0.001	H_0 rejected
	Positive Ranks	34	17.50	595,00			
	Ties	0					
	Total	34					

Hypothesis 2: Improvement of Students' CPS Ability in the Control Group

Improvement in the control group's CPS ability was analyzed using a paired-sample t-test, as both pretest and posttest scores were normally distributed ($p > 0.05$). (Nandiyanto & Hofifah, 2024).

Table 11. Normality Test of Control Group

Class	Shapiro-Wilk			Decision	
	Statistic	df	Sig.		
Control	Pretest	0.983	35	0.843	H_0
	Posttest	0.967	35	0.377	accepted

The results indicated a statistically significant increase in CPS performance ($t = -15.669, p < 0.001$), with a mean difference of -23.30 , showing higher posttest scores compared to pretest scores. Accordingly, the null hypothesis (H_0) was rejected, indicating that direct instruction led to a significant improvement in students' CPS abilities.

Table 12. Paired Sample T-Test

Pair		Paired Differences					t	df	Sig. (2-tailed)	Decision
		Mean	Std. Deviation	Std. Error	95% Confidence Interval of the Difference					
					Lower	Upper				
1	Pretest- Posttest	-23.30057	8.79766	1.48708	-26.32267	-20.27847	-15.669	34	<0.001	H_0 rejected

Hypothesis 3: Comparison of Students' CPS Ability Between the Experimental and Control Groups

Post-intervention CPS abilities were compared using the Mann–Whitney U test due to non-normality of the experimental group's posttest data (Park, 2025). The results revealed that the experimental group achieved a significantly higher CPS performance than the control group ($mean\ rank = 51.97; 18.51; U = 18.00, p < 0.001$). Therefore, H_0 is rejected, indicating that students' CPS ability in the

experimental group was significantly higher than that of the control group. The results are presented in the following table.

Table 13. Mann Whitney U-Test

		Ranks			Test Statistics ^a				
	Class	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Wilcoxon W	Z	Asym p. Sig. (2-tailed)	Decision
Posttest	Experiment	34	51.97	1767.00	18.000	648.000	-6.928	< 0.001	H_0 rejected
	Control	35	18.51	648.00					
	Total	69							

N-Gain and Effect Size Cohen's D in Students' CPS Ability

The effectiveness of the intervention was evaluated using normalized gain (N-gain) to compare CPS improvement between groups (Westphale et al., 2022).

Table 14. Overall N-gain result.

	N	N-Gain Score	Category
Experiment	34	0.7921	High
Control	35	0.2970	Low

As shown in Table 13, the experimental group achieved a high mean N-gain (0.7921), whereas the control group attained a low N-gain (0.2970), indicating that students in the experiment group experienced a higher increase in CPS ability compared to students in the control group. Since some N-Gain tests have been criticized for being "prescore biased," further testing with Cohen's D effect size will be conducted to avoid this problem by focusing on standardized mean differences that more meaningful than statistical significance alone (Coletta & Steinert, 2020). The results of Cohen's D in the control class showed a value of 2.438 and the experimental class showed a value of 5.893 in the 'huge' category ($d > 2$) with a higher increase in the experimental class compared to the control class (Sawilowsky, 2009). However, these results need to be interpreted with caution, considering other factors that could potentially influence the results beyond the learning treatment provided.

The item-level improvements from pretest to posttest are illustrated in the following figure.

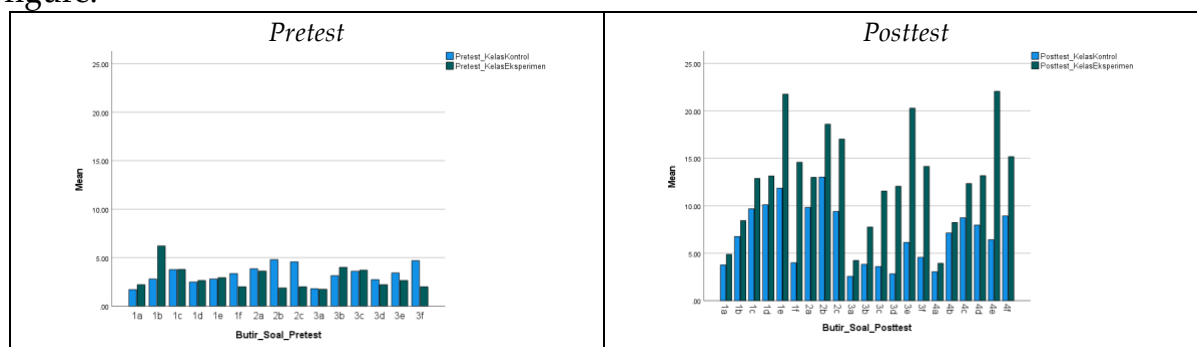


Figure 2. Comparison of Item Scores Pretest and Posttest in Both Class

The pretest results indicate a relatively uniform and low score distribution, with scores ranging from 1 to 6 points across both *Knowledge Acquisition* items (1a–1e, 2a, 3a–3e) and *Knowledge Application* items (1f, 2b, 2c, 3f), suggesting that students’ initial abilities to acquire and apply knowledge for CPS were limited. In contrast, the posttest results show a wider score distribution, ranging from 5 to 23 points, with more substantial improvements observed in the experimental group than in the control group across both CPS indicators, namely *Knowledge Application* (items 1f, 2b, 2c, 3f, and 4f) and *Knowledge Acquisition* (items 1a–1e, 2a, 3a–3e, and 4a–4e). The percentage distribution of students’ scores across indicators is presented in following figure.

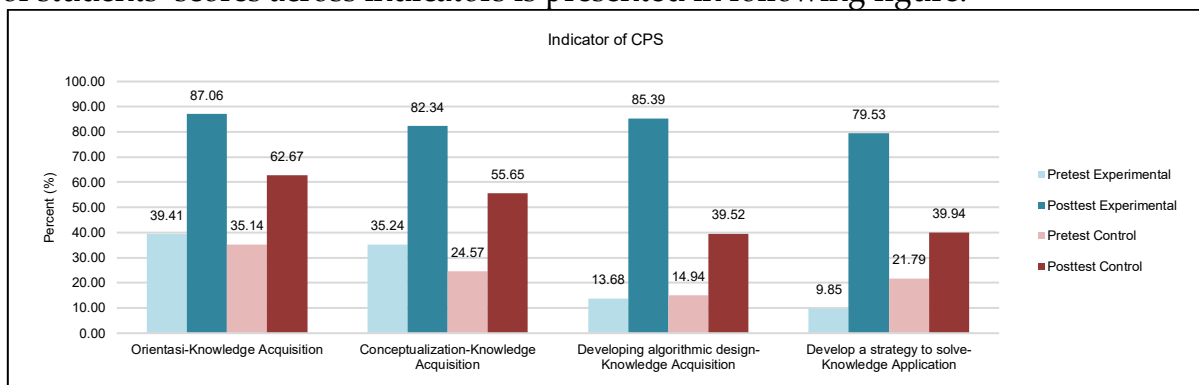


Figure 3. Percentage Distribution of CPS (%)

Discussion

Students’ Complex Problem Solving (CPS) Ability

The pretest results showed that students’ CPS abilities in both groups were well below the minimum criteria, with an average score of 18.55 in the experimental class and 21.09 in the control class. These findings confirm the initial observations that less than half of the students were able to achieve above-average CPS abilities, and only a small proportion were able to relate mathematical concepts to climate change issues meaningfully. This condition aligns with PISA 2022 findings, which reported that only 18% of Indonesian students achieved Level 2 mathematics proficiency, indicating limited CPS abilities in real-world contexts.

Table 15. Pretest-Posttest Analysis

Pretest	Posttest
<p>(A)</p>	<p>(B)</p>
Translate Picture (A):	Translate Picture (B):
	a. What is asked: how does fertilizer affect plant height?

<i>Pretest</i>	<i>Posttest</i>
<p>a. What is asked: how does sunlight affect the height growth of microgreens?</p> <p>b. The independent variable is light, the dependent variable is microgreen plants, photosynthesis.</p> <p>c. The relationship between the variables: microgreen plants will grow optimally if they receive sufficient light every day through photosynthesis.</p> <p>d. The required plan.</p> <p>e. Slope and intercept.</p> <p>f. Prediction of plant height at 14 hours and conclusion. Duration of exposure: 2, 4, 6, 8, 10, 12, 14 Plant height: 3.5, 5, 5.5, 6, 7, ..., 9 Conclusion: the longer the plants are exposed, the taller the plants grow.</p>	<p>b. The independent variable is plant fertilizer, x weeks. The dependent variable is plant height in centimeters.</p> <p>c. The fertilizer given to the plants affects different plant heights.</p> <p>d. The required plan: determine the independent variable x and the dependent variable; Calculate the required summary statistics; Calculate the slope b; Calculate the intercept a; Form the regression equation; Write the interpretation of the calculation results.</p> <p>e. Group A. (Using the linear regression equation), the equation obtained is $y = a + bx$ so $y = 1.39 + 1.46x$ Group B. (Using the linear regression equation) the equation obtained is $y = a + bx$ so $y = 1.46 + 0,77x$</p> <p>f. The conclusion is that the more fertilizer is applied to plants, it will affect plant height. However, it is still necessary to consider the environmental impact on greenhouse gas emissions.</p>

Table 14 on Translate Picture (A) shows that students were able to identify the problem in question (a) well according to the **Orientation** indicator. However, in question (b), there were still errors in selecting the dependent and independent variables about microgreen growth, indicating that the concept of **Conceptualization** was not well understood. This is also supported by the students' inaccuracy in connecting the variables related to microgreen growth in point (c). The **Developing Arithmetic Design** indicator is shown by students not writing down the relevant plans and steps to build a linear regression model as should appear in points (d) and (e). This condition indicates a low level of **Knowledge Acquisition**. Point (f) shows that students use inappropriate reasoning because they do not apply the concept of linear regression and are not yet able to relate it to the context of climate change in the indicator **Develop Strategy to Solve**.

The student's statement "*the longer the plants are exposed, the taller the plants grow*" shows that the student has returned to the stage of connecting existing information or conceptualization, which should have developed to the stage of knowledge application. This shows that the aspect of **Knowledge Application** in the student's answer is still not optimally fulfilled. On Translate Picture (B), students were able to identify the problem in point (a), namely the effect of fertilizer on plant height, thus fulfilling the **Orientation** indicator. In point (b), students also correctly determine the independent and dependent variables, namely plant fertilizer as the independent variable and plant height in centimeters as the dependent variable. This shows that the **Conceptualization** process has developed well because students are able to

understand the structure of the problem and identify the relevant variable components.

This is supported in point (c) where students connect the two variables by stating that fertilizer application affects plant height, and some students even write about the types of correlation and cause-and-effect relationships. In point (d), students systematically develop a solution plan to form a linear regression, followed by point (e) where students successfully form an appropriate and structured linear regression model. These steps show that the **Developing Arithmetic Design** indicator has been met and reflects the development of the **Knowledge Acquisition** aspect. In point (f), from the linear regression obtained, students concluded that the more fertilizer given, the taller the plants would grow, and began to associate these results with environmental impacts, particularly greenhouse gas emissions.

This shows that students not only understand the relationship between variables but are also able to interpret the model results in a broader context. These findings indicate that the indicator for **Develop Strategy to Solve** problems has been met and reflects the development of **Knowledge Application**. Thus, the students' answers on sheet (B) show that the processes of knowledge acquisition and knowledge application within the CPS framework have developed more optimally than those on answer sheet (A). This shows that direct experience of climate change's impacts does not automatically develop CPS skills. In fact, mathematics plays a strategic role in understanding climate change through data analysis, modeling, and prediction (Hauge et al., 2021).

Students' CPS Ability in PBL-STEM approach supported by DMS Instruction and Direct Instruction within a Climate Change Context

The results showed that both groups experienced an increase in CPS ability, with a more significant increase in the experimental class compared to the control class. These findings indicate that DMS-assisted STEM-based PBL learning has a more effective impact. The use of DMS encourages students to think dynamically and conceptually, not limited to mathematical procedures.

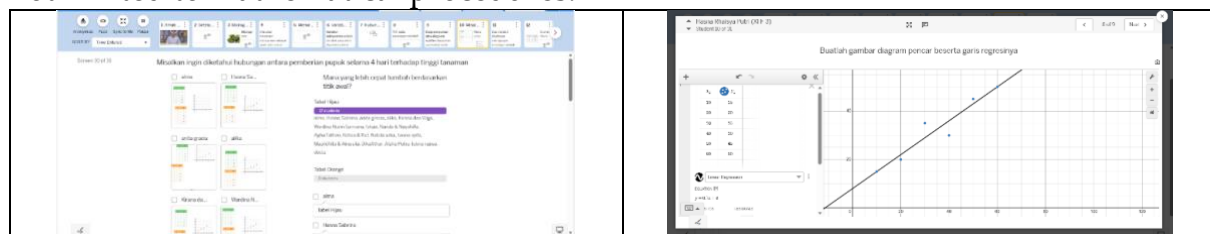


Figure 4. Student Responses and Graphical Exploration of Linear Regression Models
Figure 4 shows that DMS (Desmos) provides a graphing calculator feature that allows students to explore linear regression equations based on data in scatter plots. This visualization helps students better understand the relationship between variables. The results of the work can be sent and displayed on the teacher's dashboard in real time, making it easier to monitor students' thinking processes. Students can also see their

peers' responses, which encourages interaction, reflection, and more meaningful classroom discussions. Thus, the use of DMS supports the PBL-STEM stages, particularly in individual investigation, solution development and presentation, and evaluative reflection. Additionally, the use of DMS strengthens the integration of Technology, Engineering, and Mathematics aspects within the STEM framework. These findings align with research indicating that DMS has a larger effect size on problem-solving skills than on other skills (He et al., 2025a).

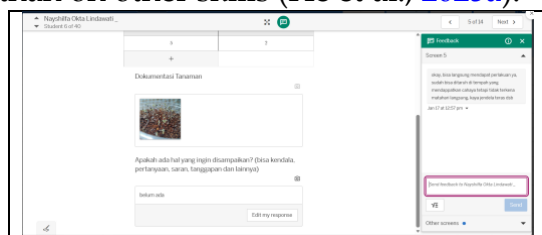


Figure 5. Feedback Real-Time Features

As shown in Figure 5, Desmos also provides a real-time feedback feature that allows teachers to monitor learning progress continuously. The read indicator shows that students have read the feedback provided, enabling a more focused learning process.

This feature supports the organization of students and group investigation in PBL-STEM, especially in monitoring strategies and deepening understanding of problems. In addition, this digital interaction strengthens the integration of Science aspects because students can discuss empirical obstacles, for example, in the process of planting microgreens. In general, the integration of technology in learning has a stronger impact than direct learning, especially in the context of climate change issues. These findings are in line with previous literature stating that digital tools that are interactive can increase dynamic and meaningful learning (Cheung & Slavin, 2013; Kravitz et al., 2022).

These results are supported by a number of previous studies showing that DMS significantly improves mathematical modeling, reasoning, and complex problem-solving skills, with moderate to large effect sizes across various educational levels (Fissore et al., 2021; Ji et al., 2024; Juandi et al., 2021; Latifi et al., 2022). Furthermore, DMS has also been found to be most impactful in mathematics learning by improving students' conceptual understanding, motivation, and performance in geometry, algebra, and calculus, including in the context of STEM education (Adelabu et al., 2022; Mierluş-Mazilu & Yilmaz, 2024; Yorganci, 2023). Thus, DMS not only strengthens the mastery of mathematical concepts but also supports the analysis and interpretation of climate change data in an applied manner.

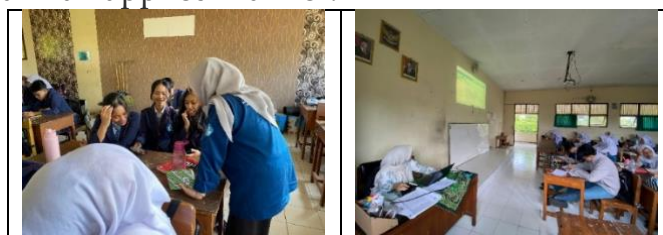


Figure 6. Classroom Learning Process Using Desmos

The application of the DMS-assisted PBL-STEM model in the experimental class achieved mastery because each stage of learning systematically facilitated the development of CPS. The problem orientation and student organization stages helped students understand contextual problems and relevant STEM concepts, thereby supporting *Knowledge Acquisition*. The integration of STEM in learning can be seen in the following table:

Table 16. STEM Aspects in the Learning Process

STEM	Activity
Science	Examining the effects of environmental factors on microgreen growth and their implications for climate change
Technology	Utilizing dynamic mathematics software (desmos) for data measurement and analysis
Engineering	Designing and optimizing microgreen growth systems
Mathematics	Analyzing relationships among growth variables using graphs and linear regression lines

The investigation stage, both individual and group, allows students to explore and model problems dynamically with the support of DMS. In the development and presentation stage, students apply the strategies they have designed to produce appropriate solutions as a form of *Knowledge Application*. Reflection and evaluation at the end of the learning process further strengthen students' ability to assess the effectiveness of the solutions produced. These findings are consistent with research showing that the integration of DMS in PBL significantly improves student learning engagement, academic achievement, and mathematical reasoning (Gülburnu, 2025). Meanwhile, the control class that applied the direct learning model also achieved mastery, especially in terms of *Knowledge Acquisition*. The presentation of material and structured exercises effectively helped students understand the basic concepts that form the foundation of problem solving.

Guided and independent exercises further facilitated the application of concepts and mathematical reasoning in the context of everyday problems as a form of *Knowledge Application*. However, the teacher-centered approach limited students' active involvement in exploration and deep reflection. Relatively low participation in discussions and a tendency to rely on peers hindered the development of independent problem-solving strategies. As a result, although direct learning was effective in strengthening *Knowledge Acquisition*, the development of *Knowledge Application* in CPS skills was not optimal. These findings are in line with previous studies showing that direct learning is more effective in reinforcing conceptual understanding but is less optimal in encouraging deep and independent *Knowledge Application* compared to student-centered learning models (Arifin et al., 2020; Hermawan et al., 2020; Yaghmour & Obaidat, 2022).

Effectiveness of STEM Learning in the Context of Climate Change

The results of the study indicate that the implementation of STEM learning significantly improves students' CPS abilities. This is evidenced by hypothesis testing

and higher N-Gain scores in the experimental group (0.79) compared to the direct learning group (0.29), even though both groups used the context of climate change. These findings are consistent with previous studies reporting that STEM learning has a positive impact on CPS development (Vithanage & Nakashima, 2025; Wu et al., 2023). In addition, the integration of STEM in the context of climate change has been shown to strengthen students' conceptual understanding and problem-solving skills. (Abdurrahman et al., 2023; Batchelder et al., 2023; Johnson et al., 2023).

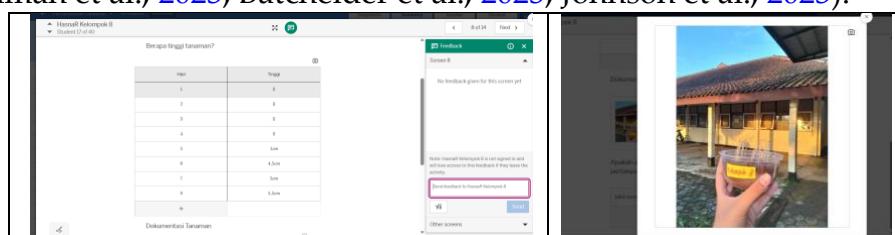


Figure 7. Monitoring Microgreen Growth as Part of a STEM-Based Learning Activity Although both classes addressed the issue of climate change, the learning design in the experimental class was more dynamic through the integration of DMS (Desmos) in the PBL-STEM model.

In the problem orientation stage, students were introduced to the issue of microgreen growth as part of food security in climate change mitigation through interactive media. Next, in the investigation stage, students collaboratively documented daily plant growth in tables and graphs using Desmos, while teachers facilitated experiments and provided real-time feedback. This process encourages active engagement in data exploration, mathematical visualization, and reflective discussion that links the concept of linear regression to real-world phenomena. This learning environment systematically supports the development of *Knowledge Acquisition* and *Knowledge Application* within the CPS framework.



Figure 8. Presentation and Structured Practice Stages in the Control Class

In contrast, in the control class, the context of food security was conveyed through a presentation of material followed by an explanation of simple linear regression. The activity continued with structured exercises, guided exercises, and independent assignments based on contextual questions. Although this approach helped students master basic concepts, learning tended to be procedural and teacher-centered, with closed-ended problems and predetermined solution strategies.

This condition limited students' opportunities to identify problems independently, evaluate alternative solutions, and integrate concepts with real contexts. As a result, CPS development—particularly in the aspect of *Knowledge*

Application—was not optimal, as reflected in the relatively low N-Gain scores. These findings are consistent with studies showing that direct instruction provides less of the hands-on and experiential learning essential for developing problem-solving skills (González et al., 2024; Narsareddygar & Naik, 2025; Rathi & Nirgude, 2021). Overall, these findings indicate that a STEM-based approach supported by DMS is more effective than direct instruction in enhancing students' CPS skills within a climate change context.

Conclusions and Suggestions

This study demonstrates that a STEM-based approach supported by Dynamic Mathematics Software (DMS) is more effective than direct instruction in enhancing senior high school students' Complex Problem Solving (CPS) skills within a climate change context. By integrating real-world problems with interactive mathematical visualizations, the approach strengthens both *Knowledge Acquisition* and *Knowledge Application*. The findings contribute theoretically by extending existing theories in mathematics education and CPS, demonstrating that the integration of technology through DMS not only reinforces existing pedagogical frameworks but also challenges traditional methods by providing a dynamic medium for CPS development. This study confirms the significant impact of DMS-supported STEM learning on CPS skills, emphasizing its alignment with contemporary educational demands for addressing complex global challenges. Nevertheless, the quasi-experimental design and the relatively small sample size may limit the generalizability of these findings. Accordingly, future research is recommended to involve larger and more diverse samples, examine long-term learning effects, and explore the role of teacher readiness and technological infrastructure in supporting CPS-oriented instruction. Overall, the study highlights the importance of innovative, technology-enhanced STEM learning in preparing students to engage in reflective, evidence-based problem solving when confronting complex global issues such as climate change.

Limitations

This study has limitations that need to be considered when interpreting the results. The pretest and posttest reliability coefficients, which are classified as moderate reliability, are influenced by the characteristics of the instrument, which consists of only one question measuring two indicators, while each other question is designed to measure all CPS indicators. The complexity of these ability indicators, as well as the limited number of items, caused students to use different completion strategies, thereby reducing internal consistency between items. Therefore, further research is recommended to develop instruments with a larger number of items and refine the scoring rubric in order to obtain more stable reliability estimates. In addition, this study was limited to Problem-Based Learning as a syntax to apply the STEM approach supported by a single Dynamic Mathematics Software platform, Desmos, the

generalizability of the findings may be limited. The sample size was relatively small, and the study was conducted at only one educational site, which may not represent broader educational settings. Future research is encouraged to explore other instructional models to apply the STEM approach and utilize various DMS platforms to strengthen the generalizability and robustness of these findings.

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