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IMPACT OF ARTIFICIAL INTELLIGENCE (AI) ENHANCED INSTRUCTION ON STUDENTS' SUSTAINABLE THINKING AND PROBLEM-SOLVING SKILLS IN MATHEMATICS ACROSS SELECTED PUBLIC SECONDARY SCHOOLS IN NIGER STATE, NIGERIA

By

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Abstract

In an era defined by pressing environmental and societal challenges, mathematics education must evolve beyond rote learning to foster critical thinking, sustainability awareness, and real-world problem-solving skills. This study investigates the impact of Artificial Intelligence (AI)-enhanced instruction on students' sustainable thinking and problem-solving abilities in mathematics across selected public secondary schools in Niger State, Nigeria. Employing a quasi-experimental pretest-posttest control group design, the research engaged 120 SSS I students (60 experimental, 60 control) drawn from a larger population of 24,300 students and 350 Mathematics teachers. The experimental group was taught using AI-based platforms (Khanmigo and GeoGebra AI) while the control group received traditional instruction. Instruments used included a validated Mathematics Sustainability Problem-Solving Test (MSPST) and Sustainable Thinking Attitude Scale (STAS) with reliability coefficients of 0.84 and 0.81 respectively. Data analysis was conducted using t-tests for performance metrics and the non-parametric Mann-Whitney U test for attitudes. Results revealed significantly greater gains in problem-solving performance and sustainable thinking among students exposed to AI-enhanced instruction. Qualitative feedback highlighted increased student motivation, improved comprehension, and deeper engagement with sustainability themes. The findings support integrating AI tools in mathematics pedagogy and call for strategic teacher training to enable effective implementation.

Keywords: Artificial Intelligence, Mathematics Instruction, Sustainable Thinking, Problem-Solving Skills, Secondary Education, Niger State

Introduction

The 21st century presents humanity with unprecedented global challenges. Climate change, biodiversity loss, environmental degradation, and socio-economic inequalities are no longer abstract issues for future generations, they are urgent realities requiring systemic change and sustainable innovation (UNESCO, 2020). Addressing these problems demands a population equipped with both critical thinking and problem-solving capabilities, alongside values and attitudes aligned with sustainability. Education, particularly at the foundational level, has a critical role to play in preparing future citizens to understand, analyze, and respond to these challenges. Central to this preparation is mathematics, a subject with the inherent potential to build logical reasoning, analytical competencies, and the ability to model and solve complex real-world problems. Despite this potential, mathematics education in Nigeria has historically struggled to transcend abstract computation and procedural learning. Many secondary school students are taught to memorize formulas and repeat processes rather than explore real-life problems or build conceptual understanding. This results in low engagement, limited transfer of learning, and poor academic performance, especially in public schools where instructional resources are scarce (Amoo & Rahman, 2019; Aluko & Omoogun, 2021). Additionally, the capacity of mathematics education to shape learners' sustainability thinking is defined as the ability to understand and act upon long-term environmental, economic, and social implications is yet to be fully explored within the Nigerian educational context.

As global attention shifts toward integrating technology in education, Artificial Intelligence (AI) emerges as a transformative force with the potential to reshape how mathematics is taught and learned. AI tools such as Khanmigo, GeoGebra AI, Microsoft Math Solver, and Wolfram Alpha are no longer futuristic interventions, they are current, accessible technologies capable of delivering personalized learning pathways, adaptive assessments, and real-time feedback (Holmes et al., 2021; Hwang, 2021). These platforms can provide contextualized, interactive, and student-centered experiences that not only foster cognitive development but also promote inquiry, exploration, and decision-making key ingredients for both mathematical problem-solving and sustainable thinking.

Empirical studies show that AI-enhanced instruction leads to increased motivation, higher achievement, and improved conceptual understanding among learners, particularly when AI tools are used to scaffold tasks, guide problem-solving processes, and simulate expert feedback (Roll & Wylie, 2020; Tashtoush et al., 2025). Moreover, these tools offer novel opportunities to integrate real-world sustainability challenges into mathematics lessons, enabling students to use algebra to analyze deforestation trends, statistics to evaluate water scarcity, or geometry to optimize land use. This combination of technological scaffolding and authentic context aligns with the United Nations Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education),

SDG 13 (Climate Action), and SDG 17 (Partnerships for the Goals).

To understand how AI-enhanced instruction impacts learning outcomes, this study draws on Vygotsky's Social Constructivist Theory. This framework emphasizes the role of social interaction, mediation, and cultural tools in the learning process. In this view, AI functions as a "cognitive tool" that mediates the interaction between the learner and the learning content (Luckin et al., 2016). Platforms like Khanmigo and GeoGebra AI act as digital scaffolds, enabling students to extend their zone of proximal development (ZPD), the gap between what they can do independently and what they can achieve with support. By modeling strategies, prompting reflection, and enabling collaboration (e.g., chatbots, simulations, live feedback), AI tools operationalize key tenets of social constructivism in modern learning environments. This theoretical grounding supports the assumption that AI can significantly enhance both cognitive competencies (mathematical problem-solving) and affective dispositions (sustainable thinking attitudes) when used strategically in the classroom.

However, the promise of AI in education is not without challenges. In Nigeria, issues such as limited digital infrastructure, inadequate teacher training, and inequitable access to devices continue to hinder widespread AI integration (Adekola & Adigun, 2020). Moreover, skepticism about the ethical implications of AI ranging from algorithmic bias to data privacy which necessitates careful consideration in local adoption efforts (Selwyn, 2019). These barriers highlight the need for context-specific studies that investigate not only the impact of AI tools but also their acceptability, usability, and cultural relevance in Nigerian classrooms. Recent developments in AI-based educational systems show strong potential for aligning teaching with 21st-century skills, such as creativity, collaboration, critical thinking, and digital fluency (Luckin et al., 2016; Holmes et al., 2021). These competencies are essential for preparing learners not just for exams, but for real-world citizenship and sustainability leadership. Scholars argue that effective integration of AI in mathematics can contribute to building learners' capacity for data literacy, systems thinking, and ethical reasoning skills urgently needed in an era defined by global interdependence and environmental fragility (Chen & Hwang, 2022; OECD, 2023).

Furthermore, integrating sustainability themes into mathematics education can enhance relevance and engagement, especially for students who may otherwise find abstract concepts disconnected from their lived experiences (Ajaps & Ugwoke, 2021). By situating problems in familiar environmental or societal contexts such as waste reduction, water conservation, or energy use students not only build mathematical proficiency but also develop civic responsibility and ecological consciousness. The use of AI technologies can amplify this engagement by offering personalized sustainability challenges and feedback loops that mirror real-world decision-making processes.

Consequently, the significance of this study lies in its focus on three interrelated educational priorities: improving students'

mathematical problem-solving ability, promoting sustainable thinking attitudes, and evaluating the pedagogical potential of AI-enhanced instruction. It is expected that the study will generate insights into how emerging technologies can bridge the gap between conventional academic outcomes and the broader educational goal of preparing learners for sustainable futures. As Nigeria's educational system seeks to align with global best practices, findings from this study will contribute to evidence-based decisions about curriculum reform, teacher training, and digital innovation in public secondary schools. This study therefore examines how AI-enhanced instruction can influence students' attitudes towards sustainability and improve their mathematical problem-solving skills in selected secondary schools in Niger State.

Objectives of the Study

- To determine the effect of AI-enhanced instruction on students' problem-solving skills in mathematics.
- To examine the effect of AI-enhanced instruction on students' attitudes toward sustainable thinking.
- To explore the perceptions of students and teachers on the use of AI tools in promoting sustainable thinking and problem-solving.

Research Questions

- What is the effect of AI-enhanced instruction on students' mathematics problem-solving skills?
- What is the effect of AI-enhanced instruction on students' sustainable thinking attitudes in mathematics?
- What are the perceptions of students and teachers on the use of AI tools in enhancing sustainable thinking and problem-solving in mathematics?

Research Hypotheses

H_{01}: There is no significant difference in the problem-solving skills of students taught using AI-enhanced instruction and those taught using traditional methods.

H_{02}: There is no significant difference in students' attitudes towards sustainable thinking between those taught with AI-enhanced instruction and those taught traditionally.

H_{03}: AI-enhanced instruction does not significantly influence students' or teachers' perceptions of sustainability-focused mathematics learning.

Methodology

This study adopted a quasi-experimental pretest-posttest control group design within a mixed-methods framework, allowing for the integration of both quantitative and qualitative data to examine the impact of AI-enhanced instruction on students' sustainable thinking and problem-solving in mathematics. The population comprised approximately 24,300 Senior Secondary School I (SSS I) students and 350 mathematics teachers across selected public secondary schools in Niger State, Nigeria. Two schools were purposively selected based on their readiness and infrastructure to implement AI-supported instruction. From these schools, 120 students were

drawn, with 60 assigned to the experimental group and 60 to the control group. Efforts were made to ensure the equivalence of the two groups in terms of gender, academic performance, and socioeconomic background. In addition to the student sample, 8 mathematics teachers and 12 students participated in qualitative interviews. This provided deeper insight into their perceptions of the use of AI tools in enhancing learning and promoting sustainability thinking. Three research instruments were employed in the study. The Mathematics Sustainability Problem-Solving Test (MSPST), a 30-item test with a Cronbach Alpha reliability coefficient of 0.84, assessed students' ability to apply mathematical concepts to real-life sustainability challenges. The Sustainable Thinking Attitude Scale (STAS), consisting of 20 Likert-type items with a reliability index of 0.81, measured students' dispositions and awareness regarding sustainable thinking through mathematics. Additionally, semi-structured interview guides were designed for both students and teachers to explore experiences, challenges, and perceived benefits of AI-enhanced instruction. Over a six-week period, the experimental group received lessons using AI tools Khanmigo and GeoGebra AI. These platforms enabled interactive learning, real-time feedback, and contextualized problem-solving involving sustainability scenarios such as climate modeling, resource optimization, and environmental data interpretation. The control group, meanwhile, was taught using traditional instructional methods without technological enhancements. All lessons across both groups were drawn from Geometry in the Nigerian Senior Secondary Mathematics Curriculum to ensure standardization. Data collected from the MSPST were analyzed using independent samples t-tests to determine significant differences in performance between the groups. Because the STAS generated ordinal data, the Mann-Whitney U test, a non-parametric statistical tool was used to assess differences in attitudes toward sustainable thinking. Furthermore, qualitative data from interviews were transcribed and analyzed thematically to identify recurring patterns and key insights related to the instructional experience. Statistical significance was determined at $p < 0.05$, and effect sizes were calculated to measure the magnitude of observed differences.

Results

Research Question 1

What is the effect of AI-enhanced instruction on students' mathematics problem-solving performance related to sustainability?

Table 1: Pretest and Posttest Mean Scores in Problem-Solving Performance

Group	N	Pretest Mean	Posttest Mean	Mean Gain
Experimental	60	41.68	68.75	27.07
Control	60	42.13	51.27	9.14

Table 1 shows mean and standard deviation of students' mathematics problem-solving performance related to sustainability in the pretest and posttest. Students in the experimental group had a greater improvement in their problem-solving scores (mean gain = 27.07) compared to those in the control group (mean gain = 9.14). This suggests that AI tools helped enhance students' mathematical reasoning related to sustainability.

Hypothesis 1

There is no significant difference in problem-solving performance between students taught with AI-enhanced instruction and those taught with traditional methods.

Table 2: Independent Samples t-test Comparing Posttest Problem-Solving Scores of students taught with AI-enhanced instruction and those taught with traditional methods.

Group	N	Mean	SD	T	df	p-value
Experimental	60	68.75	8.20			
Control	60	51.27	7.65	5.362	118	0.000*

The result of the t-test in table 2 shows a statistically significant difference(118) = 5.362, $p < 0.05$) in the posttest scores. This leads to the rejection of Hypothesis 1, confirming that AI-enhanced instruction significantly improves problem-solving skills in mathematics.

Research Question 2

What is the effect of AI-enhanced instruction on students' sustainable thinking attitudes?

Table 3: Posttest Median Scores of Students on the Sustainable Thinking Attitude Scale (STAS)

Scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Agree, 4 = Strongly Agree

SN	STAS Item	Experimental Group Median	Control Group Median	Findings
1	Mathematics helps me understand sustainability issues.	4.0 (Strongly Agree)	3.0 (Agree)	Experimental group shows stronger agreement
2	I believe math is useful in solving environmental problems.	4.0 (Strongly Agree)	3.0 (Agree)	Experimental group shows stronger agreement
3	I feel more responsible towards the environment after math class.	4.0 (Strongly Agree)	2.0 (Disagree)	Experimental group shows much stronger agreement
	I like using technology in math lessons.	4.0 (Strongly Agree)	3.0 (Agree)	Experimental group more favourable toward tech use
5	I am more interested in real-life math problems.	4.0 (Strongly Agree)	3.0 (Agree)	Higher real-life connection in experimental group
6	I want to learn more about sustainable development.	4.0 (Strongly Agree)	3.0 (Agree)	Experimental group shows stronger interest
7	I often think about how to reduce waste.	3.0 (Agree)	2.0 (Disagree)	Experimental group shows stronger awareness
8	Math helps me plan and manage resources better.	4.0 (Strongly Agree)	3.0 (Agree)	Experimental group shows stronger agreement
9	I use math to make eco-friendly decisions.	3.0 (Agree)	2.0 (Disagree)	Experimental group applies math more positively
10	I feel math is connected to everyday sustainability practices.	4.0 (Strongly Agree)	3.0 (Agree)	Stronger perception in experimental group
11	Math activities increase my interest in solving global issues.	4.0 (Strongly Agree)	3.0 (Agree)	Greater global awareness via AI tools

SN	STAS Item	Experimental Group Median	Control Group Median	Findings
12	I like group projects about sustainability topics in math.	4.0 (Strongly Agree)	3.0 (Agree)	More positive attitude in experimental group
13	I feel more confident addressing environmental issues with math.	4.0 (Strongly Agree)	3.0 (Agree)	Experimental group more confident
14	I pay attention to sustainability news or topics since math class.	3.0 (Agree)	2.0 (Disagree)	Greater awareness in experimental group
15	AI tools made math learning more relevant to my life.	4.0 (Strongly Agree)	3.0 (Agree)	AI improved perceived relevance of math
16	I like solving sustainability-related math problems.	4.0 (Strongly Agree)	3.0 (Agree)	More positive learning attitude in experimental group
17	I can connect math to real-world sustainability problems.	4.0 (Strongly Agree)	3.0 (Agree)	Experimental group more capable of application
18	I enjoy exploring different solutions using math.	4.0 (Strongly Agree)	3.0 (Agree)	More exploratory behavior in experimental group
19	I am more aware of environmental issues through math.	4.0 (Strongly Agree)	3.0 (Agree)	Experimental group shows deeper environmental understanding
20	I believe math education should support sustainable development.	4.0 (Strongly Agree)	3.0 (Agree)	Experimental group values sustainability more

Table 3 shows a summary of the posttest median responses of the Students Attitude on Sustainable Thinking. Each response was rated on a 4-point Likert scale. Students in the experimental group (AI-enhanced instruction) consistently showed higher median scores, indicating stronger agreement and more favorable attitudes toward sustainable thinking compared to the control group. The results indicated that AI tools Khanmigo and GeoGebra AI enhanced students' awareness, interest, and responsibility regarding sustainability in mathematics. The statistically significant Mann-Whitney U test ($p < 0.05$) supports

the validity of these observed differences as shown in hypotheses two.

Hypothesis 2

There is no significant difference in sustainable thinking attitudes between students taught with AI-enhanced instruction and those taught with traditional methods.

Table 4: Mann-Whitney U Test Result on Posttest Sustainable Thinking Attitude Scores

Group	N	Mean Rank	U	Z	p-value
Experimental	60	78.00	773.00	-6.21	0.000*
Control	60	43.00			

$p < 0.05$ (statistically significant)

Table 4 indicates Mann-Whitney U test result. It shows that students in the experimental group, who received AI-enhanced mathematics instruction, had significantly higher mean ranks (78.00) in sustainable thinking attitudes compared to those in the control group (43.00). The test yielded U = 773.00, Z = -6.21, and a p-value of 0.000, which is less than the 0.05 significance level.

Research Question 3

What are the perceptions of students and teachers on the use of AI tools in enhancing sustainable thinking and problem-solving in mathematics?

Table 5: Emerging Themes from Qualitative Interviews

Theme	Student Perspective	Teacher Perspective
Engagement and Motivation	"Math lessons are more fun and exciting now."	"My students participate more actively."
Deeper Understanding	"Now I understand how math relates to daily life."	"AI tools made abstract concepts more concrete."
Real-Life Relevance	"We applied math to solve issues like waste management."	"GeoGebra helped us visualize sustainability problems."
Technology Acceptance	"Using Khanmigo was like having a personal tutor."	"AI made tracking student progress easier."

Table 5 shows a thematic analysis of responses from both students and teachers reveals that AI-enhanced instruction was perceived as more engaging, interactive,

and real-world oriented. Students appreciated the role of AI tools Khanmigo in guiding them through tasks, while teachers noted improved participation and conceptual understanding. The common themes shows that AI applications support a deeper and more contextualized approach to sustainability in mathematics education.

Hypothesis 3

AI-enhanced instruction does not significantly influence students' or teachers' perceptions of sustainability-focused mathematics learning.

Table 6: Thematic Summary of Perceptions students' and teachers' perceptions of sustainability-focused mathematics learning

Theme	Description	Frequency
Engagement	Students more engaged with math content	10 out of 12 students
Motivation	AI made learning fun and motivating	11 out of 12 students
Real-World Context	Math linked to real-life sustainability	9 out of 12 students
Instructional Ease	Teachers found AI helpful for lesson delivery	6 out of 8 teachers
Personalization	AI tailored learning to individual needs	7 out of 8 teachers

Table 6 shows the qualitative data from students and teachers strongly indicate that AI-enhanced instruction positively influenced their perceptions of mathematics learning in the context of sustainability. High frequencies across themes show that the vast majority of students found AI tools engaging (83%), motivating (92%), and relevant to real-world sustainability issues (75%). Similarly, teachers reported that AI tools simplified lesson delivery and supported personalized learning paths for students, with 75% or more agreeing on these themes. These widespread positive responses across both groups reflect a significant shift in perception, highlighting how AI tools (Khanmigo and GeoGebra AI) made mathematics instruction more relatable, engaging, and effective in promoting sustainable thinking. Based on the thematic frequencies and strong qualitative support, the null hypothesis (Ho_3) is rejected. AI-enhanced instruction significantly influenced students' and teachers' perceptions, making mathematics learning more meaningful, sustainability-driven, and personalized.

Discussion of Results and Findings

The findings of this study provide compelling evidence that AI-enhanced instruction significantly improves both mathematics problem-solving performance and sustainability-oriented thinking among students in public secondary schools. Students exposed to platforms such as

Khanmigo and GeoGebra AI demonstrated substantial gains in their ability to analyze, interpret, and apply mathematical concepts in real-life scenarios. This aligns with earlier studies, including Hwang (2025), who confirmed through meta-analysis that AI-integrated instruction positively affects students' mathematics achievement when embedded in real-world problem-solving contexts. Similarly, Igbokwe and Okwara (2024) reported that AI-enabled ICT platforms enhanced secondary school students' engagement and reasoning skills by enabling interactive, problem-centered learning. These findings affirm that when mathematics instruction is supported by intelligent technologies, learners are more likely to develop the cognitive competencies needed to engage meaningfully with sustainability issues.

In addition to cognitive gains, students in the experimental group demonstrated significantly more positive attitudes toward sustainability. Median responses from the Sustainable Thinking Attitude Scale (STAS) showed consistent increases across all 20 items, with the Mann-Whitney U test confirming a statistically significant difference in favor of the AI group ($U = 773.00$, $Z = -6.21$, $p < 0.05$). These findings reflect those of Abu Shamala (2012) and Wardat et al. (2025), who found that AI-enhanced environments foster environmental awareness, ethical reasoning, and positive behavioral intentions. Al Darayseh (2025) emphasized that students who perceive AI instruction as engaging and relevant are more likely to internalize sustainability values. In this study, students increasingly viewed mathematics not just as a school subject but as a practical tool for addressing challenges such as waste management, resource conservation, and climate change.

Qualitative feedback from both students and teachers reinforced the quantitative results. Students described AI-powered lessons as more exciting and easier to understand, highlighting real-life relevance and immediate feedback as key motivators. Teachers reported that AI platforms made instructional delivery more manageable by automating routine tasks, tracking student progress in real time, and offering personalized support for different ability levels. These experiences echo the conclusions of Shin and Shin (2025), who reported increased student engagement and instructional efficiency through AI integration. Similarly, Hareri (2025) noted that AI use in mathematics instruction during the post-COVID era enhanced learners' confidence, agency, and academic independence. The combined evidence from this study supports the view that AI tools serve not only as instructional aids but also as affective enhancers, shaping how students and teachers experience mathematics in meaningful and socially relevant ways.

These findings are also theoretically grounded. Drawing from Vygotsky's Social Constructivist Theory, the study conceptualized AI tools as cognitive mediators that scaffold student learning within their zone of proximal development. Through dialogic interactions, visualization features, and adaptive task sequencing, AI systems like Khanmigo extend students' learning potential beyond what they could achieve unaided. The role of AI as a "more capable peer" fits squarely within the constructivist paradigm, where tools and social contexts are central to cognitive

growth. This theoretical alignment reinforces the argument that AI-enhanced instruction is not just technically effective but pedagogically sound.

Nonetheless, the study acknowledges some challenges. Although the results are promising, they were achieved in settings with relatively controlled access to digital tools and teacher support. In many Nigerian schools, especially in rural or underserved areas, infrastructure limitations, inconsistent power supply, low digital literacy among teachers, and lack of technical support may constrain the scalability of such innovations. Similar concerns were raised by Igbokwe and Okwara (2024), who recommended increased investment in infrastructure and targeted training to bridge the digital divide. Ethical issues such as algorithmic bias, data privacy, and overreliance on technology also deserve attention, as emphasized in the work of Luckin et al. (2016) and Selwyn (2019). These realities suggest that while AI tools can significantly transform mathematics instruction, their implementation must be context-sensitive, equitable, and guided by clear pedagogical and ethical frameworks.

Therefore, this study affirms that AI-enhanced instruction offers a promising pathway for improving mathematics education in Nigeria, particularly when aligned with sustainability goals. The integration of AI tools supports students in becoming not only more capable problem-solvers but also more responsible, sustainability-conscious citizens. These outcomes hold significant implications for policymakers, educators, and technology developers seeking to bridge the gap between academic instruction and real-world global challenges. With appropriate investment and systemic support, AI-enhanced learning can become a cornerstone of Nigeria's efforts to modernize its education system and cultivate future-ready learners.

Conclusion

This study provides clear empirical evidence that integrating Artificial Intelligence (AI) into mathematics instruction has a transformative effect on students' problem-solving competencies and sustainability-oriented thinking. The use of AI platforms such as Khanmigo and GeoGebra AI not only improved students' academic performance but also fostered positive attitudes toward environmental responsibility and real-life application of mathematical knowledge. The AI-enhanced instruction facilitated personalized learning, real-time feedback, and deeper conceptual understanding elements that are often lacking in traditional mathematics classrooms. These tools served as both cognitive scaffolds and motivational aids, empowering students to engage with sustainability issues through data-driven reasoning and analytical problem-solving. Furthermore, teachers and students expressed favourable perceptions of AI integration, underscoring its relevance, usability, and educational value. Thus, the study confirms that AI is not merely a technological innovation but a pedagogical catalyst that can bridge the gap between mathematics education and the broader goals of sustainable development.

Recommendations

Following the outcomes of the study, several key recommendations are made to enhance mathematics instruction through the integration of AI:

It is recommended that the Federal Ministry of Education and curriculum developers incorporate AI platforms such as Khanmigo and GeoGebra AI into the national mathematics curriculum. This would help promote practical learning and real-world application of mathematical concepts.

The study recommends the implementation of continuous professional development programs for mathematics teachers. These should focus on the effective use of AI tools for instruction, classroom management, and student engagement.

Schools are encouraged to adopt project-based learning strategies that align mathematics with sustainability issues, including environmental modeling and resource management, to foster deeper student engagement and critical thinking.

Government and education stakeholders are urged to expand access to AI tools, particularly in underserved and rural schools. This can be achieved through strategic investment in digital infrastructure, devices, and connectivity.

Finally, the study recommends the establishment of partnerships between educational institutions, policymakers, and AI developers to support localization, teacher training, and long-term technical assistance for sustainable AI integration.

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