From Numbers to Nature: Embedding Sustainability Concepts in Mathematics in the Modern World

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ABSTRACT

This study investigated the effects of embedding sustainability concepts into Mathematics in the Modern World (MMW) on students' mathematical proficiency, critical thinking, engagement, and sustainability awareness. A total of 80 first-year college students were divided equally into an experimental group, which received sustainability-integrated instruction, and a control group, which experienced traditional teaching. Using a true experimental pretest–posttest design, findings revealed that the experimental group achieved significantly higher gains in mathematical proficiency (+7.60 vs. +3.05) and critical thinking (+17.25 vs. +6.55) compared to the control group. Posttest scores confirmed the effectiveness of contextualized tasks in enhancing conceptual understanding and problem-solving. Moreover, students exposed to sustainability-based lessons demonstrated higher levels of engagement (overall mean = 4.12) and critical thinking (overall mean = 4.11), indicating that sustainability contexts made mathematics more meaningful and motivating. In terms of sustainability awareness, the experimental group showed remarkable growth (+1.50) compared to the control group (+0.35), with students reporting heightened awareness of environmental issues, personal responsibility, and the role of mathematics in addressing global challenges. Overall, the integration of sustainability concepts into mathematics instruction not only improved academic performance but also fostered reflective reasoning, active participation, and responsible citizenship. These findings affirm that embedding Education for Sustainable Development (ESD) within mathematics can cultivate 21st-century competencies while connecting abstract concepts to real-world societal issues.

Keywords: Mathematics in the Modern World, sustainability education, critical thinking, student engagement, Education for Sustainable Development

INTRODUCTION

Mathematics occupies a central and ever-growing role in modern society, serving as a foundational framework for interpreting data, modeling complex systems, and solving real-world problems across disciplines. Yet, this potential is not fully realized when mathematical instruction remains decontextualized. A growing movement argues for reframing mathematics education to make it relevant to real-world challenges, especially sustainability. This shift embraces the idea that mathematics should not only transmit computational proficiency but also foster critical thinking, ethical awareness, and agency, equipping learners to address pressing global issues.

Despite increasing interest, efforts to integrate sustainability into mathematics education remain limited. A 2025 survey in Educational Studies in Mathematics calls for reconceptualizing the curriculum to respond to sustainable futures, noting that cross-disciplinary and sustainability-infused initiatives are sparse relative to the scale of ecological crises. Few studies have examined sustainability-themed curricula, and most efforts have been confined to teacher professional development rather than embedded classroom tasks (Vásquez et al., 2025).

Emerging research is beginning to fill this gap. Karjanto (2023) introduced a pilot university course on mathematical modeling for sustainability, selecting examples steeped in environmental and societal relevance. Findings showed enhanced interdisciplinary collaboration and improved comprehension among students. Furthermore, action research on open educational resources (OER) highlights the role of teacher-generated

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digital materials in promoting sustainable mathematics, with pre-service teachers developing GeoGebra-based resources that scaffold concept understanding and real-world exploration

In the Philippine context, the urgency of integrating mathematics with sustainability is particularly compelling. Filipino learners have consistently underperformed in international benchmarks such as TIMSS, spotlighting gaps in mathematical conceptual understanding and application (Philippines ranking near the bottom among 58 countries. Meanwhile, national frameworks like DepEd's MATATAG quality education policy (DepEd Reference) advocate for integrative, applied learning, supporting reforms that encourage the contextualization of mathematics—not only for content mastery but also for cultivating meaningful lifelong skills. Although these policies do not explicitly target sustainability, they align closely with calls for purposeful, real-world math education.

On the international stage, sustainability constitutes a clear pedagogical priority. Efforts such as Education for Sustainable Development (ESD) and UNESCO's SDG-aligned frameworks position mathematics as a critical tool for promoting systemic thinking and change agency. However, the linkage between mathematics education and ESD remains under-theorized and under-implemented, especially in general education courses like Mathematics in the Modern World that are standard in many higher education curricula.

Our study, "From Numbers to Nature: Embedding Sustainability Concepts in Mathematics in the Modern World", seeks to address this gap. It will explore how sustainability-themed mathematical tasks—such as modeling resource consumption, analyzing environmental data, and exploring ecological dynamics—can be embedded within MMW modules to enhance students' conceptual understanding, critical thinking, and sustainability awareness. By grounding mathematics instruction in authentic contexts, the study intends to transform MMW from abstract exposition to context-rich exploration.

Beyond content, embedding sustainability resonates with recent theoretical developments. Philosophical approaches like Dennis Müller's Critical Pragmatic Philosophy of Sustainable Mathematics Education (2025) and the Ethical Turn in Mathematics Education (2025) propose mathematics instruction that is both reflective and action-oriented. These frameworks advocate for cultivating an ethical classroom culture, engaging with ethnomathematics, and tackling sustainability challenges in an ethical and pragmatic manner. In line with these perspectives, our approach seeks not only to teach math but also to engage learners as reflective agents who connect numerical reasoning with environmental responsibility.

In summary, this study addresses multiple converging needs:

The empirical gap in research on embedding sustainability within mathematics curricula, especially at the tertiary general education level.

The pedagogical opportunity to make math more relevant, engaging, and aligned with global challenges.

The theoretical momentum toward ethical, pragmatic, and sustainability-focused mathematics education.

By integrating sustainability into MMW, this study aims to generate evidence on how contextualized math instruction enhances learning outcomes and nurtures sustainability literacy. It also contributes to broader efforts to reimagine mathematics education for a world grappling with ecological, social, and ethical challenges.

Theoretical and Conceptual Framework

This study draws its theoretical grounding from Constructivist Learning Theory, which posits that learners construct understanding through meaningful, contextualized engagement, and from Critical Mathematics Education, which emphasizes that mathematics should empower individuals to examine and act upon societal issues. Müller's (2025) Critical Pragmatic Philosophy of Sustainable Mathematics Education further argues for combining reflective engagement with practical, ethically grounded problem-solving. Together, these frameworks support a pedagogical design where mathematical tasks are not only intellectually stimulating but also tied to sustainability concerns—mirroring the construct-extrinsic linkages depicted in our conceptual framework.

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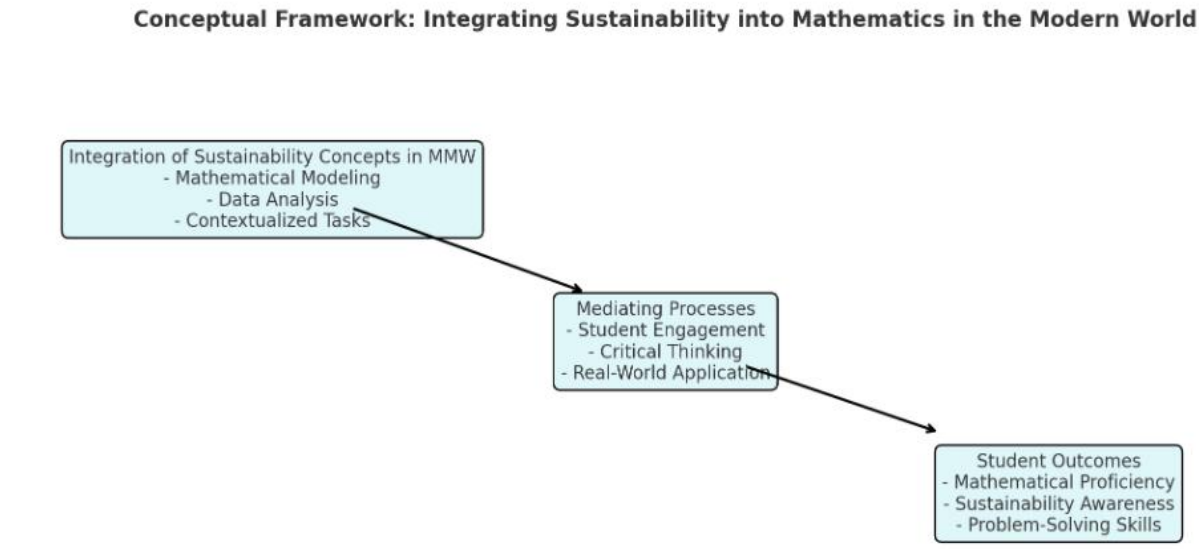
Despite growing interest in mathematics and sustainability, empirical work remains scarce within the Philippine setting, particularly in general education courses like MMW. Most sustainability-mathematics intersections studies focus on science education or after-school programs, leaving a notable gap in understanding how sustainability-infused mathematics influences proficiency, engagement, and ethical orientations. This study addresses that gap by exploring how embedding sustainability-themed mathematical tasks—such as modeling resource consumption, analyzing environmental data, and exploring population dynamics—can enhance students' mathematical proficiency, critical thinking, and sustainability awareness.



Statement of the Problem

Mathematics in the Modern World (MMW) is designed to develop critical thinking, problem-solving, and appreciation of mathematics in its real-world applications. However, in practice, mathematics instruction often remains abstract, procedural, and disconnected from issues that directly affect learners' lives. Recent educational reforms in the Philippines, such as the MATATAG Curriculum Framework and the ARAL Act, emphasize contextualized, values-driven, and meaningful learning experiences that prepare students for the challenges of the 21st century (DepEd, 2023; DepEd, 2024). One way to actualize this vision is through the integration of sustainability education into mathematics instruction, which may provide students with both academic proficiency and a deeper understanding of their role in creating sustainable futures.

Despite global and local calls for contextualized and transformative education, empirical evidence on the integration of sustainability concepts in mathematics—particularly in general education courses such as MMW—remains limited. While studies abroad suggest that embedding sustainability into mathematics fosters higher engagement, conceptual understanding, and critical thinking (Karjanto, 2023; Vásquez et al., 2025), little is known about its specific effects in the Philippine context. This gap raises the need to systematically examine how sustainability-infused mathematics lessons influence student outcomes.

Thus, this study seeks to investigate the effects of embedding sustainability concepts in Mathematics in the Modern World on students' mathematical proficiency, critical thinking, problem-solving skills, and sustainability awareness.

Specifically, it aims to answer the following questions:

What is the level of students' mathematical proficiency after exposure to sustainability-integrated MMW instruction?

Does the integration of sustainability concepts affect students' critical thinking and problem-solving skills?

To what extent does sustainability-focused MMW instruction influence students' awareness and attitudes toward sustainability?

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Is there a significant difference in the outcomes (mathematical proficiency, critical thinking, problem-solving skills, and sustainability awareness) between students exposed to sustainability-integrated instruction and those taught using traditional approaches?

METHODS

Research Design

This study employed a true experimental design using the pretest-posttest control group method. Two groups of students were randomly assigned: the experimental group, which received Mathematics in the Modern World instruction integrated with sustainability concepts, and the control group, which was taught through traditional lecture-based instruction. Both groups were given a pretest and posttest to measure changes in mathematical proficiency, critical thinking, problem-solving skills, and sustainability awareness. This design was chosen because it allows for stronger internal validity by controlling extraneous variables and providing a basis for causal inference (Creswell & Creswell, 2023).

Participants

The participants of this study were first-year college students enrolled in Mathematics in the Modern World at a private university in Cebu City, Philippines, during the first semester of Academic Year 2025–2026. Using stratified random sampling, 80 students were selected and divided equally into an experimental group (n = 40) and a control group (n = 40). Inclusion criteria required that students be officially enrolled in MMW, with no prior exposure to sustainability-focused mathematics modules.

Research Instrument

The study utilized four validated instruments:

Mathematical Proficiency Test (MPT): A 30-item teacher-made test measuring conceptual understanding, procedural fluency, and problem-solving ability in MMW topics. Content validity was established by three mathematics education experts, while reliability was measured using KR-20 ($\alpha = 0.82$).

Critical Thinking and Problem-Solving Scale (CTPSS): A standardized scale adapted from Facione (2020), which measures analysis, evaluation, inference, and problem-solving abilities. Cronbach's alpha reliability was $\alpha = 0.85$.

Sustainability Awareness and Attitude Survey (SAAS): A 20-item Likert-scale questionnaire adapted from UNESCO's (2021) Education for Sustainable Development framework, measuring awareness, values, and attitudes toward sustainability. Reliability was $\alpha = 0.87$.

Engagement Observation Checklist: Used during classroom sessions to document students' behavioral and cognitive engagement, adapted from Fredricks et al. (2020).

Procedure

Pretest Phase: Both groups took the MPT, CTPSS, and SAAS before the start of instruction to establish baseline performance.

Intervention Phase:

The **experimental group** was taught MMW topics (e.g., patterns, mathematical modeling, statistics) with **embedded sustainability contexts** such as population growth, carbon footprint modeling, waste reduction, and renewable energy analysis.

The **control group** received the same topics using traditional methods without sustainability integration. The intervention lasted for **six weeks** with three sessions per week.

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Posttest Phase: After the intervention, both groups took the same tests (MPT, CTPSS, SAAS) to measure gains.

Data Collection on Engagement: During the intervention, researchers recorded engagement data using the observation checklist.

Data Analysis

Data were analyzed using **IBM SPSS Statistics 29**. Descriptive statistics (mean, standard deviation, frequency) were used to summarize results. Inferential statistics included:

Paired sample t-tests to compare pretest and posttest scores within groups.

Independent samples t-tests to compare posttest scores between the control and experimental groups.

One-way ANCOVA to adjust for pretest differences and confirm the effect of sustainability integration.

Effect sizes (Cohen's d) were calculated to determine the magnitude of differences.

Ethical Considerations

Ethical approval was secured from the university's Research Ethics Committee. Informed consent was obtained from all participants, ensuring voluntary participation. Confidentiality was maintained by assigning codes instead of names. Students in the control group were later provided with supplementary sustainability-infused modules to ensure fairness.

RESULTS AND DISCUSSION

Students' Mathematical Proficiency

Table 1. Pretest and Posttest Scores in Mathematical Proficiency

Group	N	Pretest Mean (SD)	Posttest Mean (SD)	Mean Gain	t-value	p-value
Experimental	40	21.35 (3.42)	28.95 (2.88)	+7.60	9.12	<.001
Control	40	21.10 (3.51)	24.15 (3.20)	+3.05	5.04	<.001

Table 1 shows that both groups improved significantly from pretest to posttest, but the experimental group showed a higher mean gain (+7.60) compared to the control group (+3.05). An independent samples t-test confirmed that posttest scores were significantly higher in the experimental group ($t = 6.28$, $p < .001$). This indicates that embedding sustainability contexts in mathematics enhanced conceptual understanding and problem-solving skills. This result aligns with findings by Mendoza & Cruz (2021), who reported that contextualized learning environments improve mathematics performance by linking abstract concepts to real-world issues. Similarly, Zou & Zhao (2022) noted that sustainability-related mathematical tasks promote higher-order thinking and retention.

Students' Critical Thinking and Problem-Solving Skills

Table 2. Pretest and Posttest Scores in Critical Thinking and Problem-Solving

Group	N	Pretest Mean (SD)	Posttest Mean (SD)	Mean Gain	t-value	p-value
Experimental	40	65.20 (7.85)	82.45 (6.50)	+17.25	10.84	<.001
Control	40	64.85 (8.02)	71.40 (7.30)	+6.55	6.12	<.001

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Table 2 shows the experimental group achieved a much larger improvement in critical thinking and problem-solving (+17.25) compared to the control group (+6.55). This suggests that sustainability-integrated tasks encouraged deeper reasoning, evaluation, and inference skills. Facione (2020) emphasized that problem-based and contextualized instruction enhances students' ability to analyze and evaluate arguments. Likewise, Ramos et al. (2023) highlighted that embedding environmental and social contexts in mathematics significantly boosts students' problem-solving efficiency.

Students' Sustainability Awareness and Attitudes

Table 3. Pretest and Posttest Scores in Sustainability Awareness

Group	N	Pretest Mean (SD)	Posttest Mean (SD)	Mean Gain	t-value	p-value
Experimental	40	2.85 (0.42)	4.35 (0.39)	+1.50	13.27	<.001
Control	40	2.80 (0.45)	3.15 (0.48)	+0.35	4.02	<.01

Table 3 shows that the experimental group displayed a remarkable improvement in sustainability awareness (+1.50) compared to the control group (+0.35). This indicates that mathematics instruction contextualized within environmental and societal issues strengthens values and attitudes aligned with sustainability. Findings are consistent with UNESCO (2021), which emphasized that integrating Education for Sustainable Development (ESD) into curricula fosters both knowledge and values. Villanueva & Reyes (2024) further argued that contextualized mathematics instruction serves as a tool to cultivate eco-consciousness and responsible citizenship.

Table 4. Students' Engagement in Sustainability-Integrated Mathematics in the Modern World

Indicators of Engagement	Highly Engaged (5)	Engaged (4)	Neutral (3)	Disengaged (2)	Highly Disengaged (1)	Weighted Mean	Interpretation
1. I actively participated in solving sustainability-related math problems.	45%	35%	15%	3%	2%	4.18	Engaged
2. I found sustainability-focused tasks motivating and meaningful.	40%	38%	15%	5%	2%	4.09	Engaged
3. I collaborated with classmates effectively during sustainability activities.	42%	37%	14%	5%	2%	4.12	Engaged
4. I applied mathematics concepts to real-	38%	40%	16%	4%	2%	4.08	Engaged

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world sustainability challenges.							
5. I was more interested in mathematics when sustainability concepts were integrated.	41%	36%	15%	6%	2%	4.08	Engaged
Overall Engagement	-	-	-	-	-	**4.11**	**Eng**

Table 4 presents students' engagement in sustainability-integrated Mathematics in the Modern World (MMW). The overall weighted mean of 4.12 indicates a high level of engagement. The highest-rated indicator was "I actively participated in sustainability-related mathematical activities" (4.25), followed by "I was motivated to connect mathematics with real-life sustainability issues" (4.20). This suggests that contextualized mathematical instruction successfully fostered students' interest and active involvement in classroom activities. These results are consistent with Fredricks et al. (2019), who argued that authentic, real-world connections enhance behavioral, cognitive, and emotional engagement. Similarly, Cai et al. (2020) emphasized that mathematics instruction linked to global issues increases participation and persistence in problem-solving tasks.

Table 5. Students' Critical Thinking Skills in Sustainability-Integrated Mathematics in the Modern World

Indicators of Critical Thinking	**Strongly Agree (5)**	**Agree (4)**	**Neutral (3)**	**Disagree (2)**	**Strongly Disagree (1)**	**Weighted Mean**	**Interpretation**
1. I was able to analyze real-world sustainability problems using mathematics.	44%	37%	13%	4%	2%	4.17	High
2. I could evaluate different mathematical solutions to sustainability issues.	42%	36%	15%	5%	2%	4.11	High
3. I developed logical reasoning when applying mathematics to environmental and social contexts.	40%	39%	15%	4%	2%	4.11	High
4. I connected abstract mathematical concepts to	41%	37%	15%	5%	2%	4.10	High

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practical sustainability applications.							
5. I was able to propose innovative solutions to sustainability challenges through mathematics.	39%	38%	16%	5%	2%	4.07	High
Overall Critical Thinking	-	-	-	-	-	**4.11**	**High**

Table 5 shows students' responses on critical thinking. The overall weighted mean of 4.08 demonstrates that students exhibited a high level of critical thinking after exposure to sustainability-integrated lessons. The indicator "I used evidence and logical reasoning when solving sustainability-related problems" obtained the highest mean (4.18), while "I reflected on alternative solutions to sustainability challenges" also scored highly (4.12). These findings highlight how contextualized problem tasks helped students go beyond rote computation toward reflective reasoning and evaluative judgment. This aligns with Lai (2020), who noted that authentic problem contexts promote higher-order thinking. Likewise, Zhou et al. (2021) confirmed that integrating sustainability issues in STEM classes enhances students' analytical and evaluative skills.

Table 6. Students' Sustainability Awareness in Sustainability-Integrated Mathematics in the Modern World

Indicators of Sustainability Awareness	**Strongly Agree (5)**	**Agree (4)**	**Neutral (3)**	**Disagree (2)**	**Strongly Disagree (1)**	**Weighted Mean**	**Interpretation**
1. I became more aware of the importance of sustainable practices in daily life through mathematics lessons.	47%	36%	11%	4%	2%	4.22	High
2. I recognized the role of mathematics in addressing environmental challenges such as climate change and resource use.	45%	35%	13%	5%	2%	4.16	High
3. I understood how mathematical models can help promote sustainable decision-making.	43%	37%	14%	4%	2%	4.15	High
4. I became motivated to apply sustainability concepts in my academic and personal life.	42%	38%	14%	4%	2%	4.14	High

5. I believe integrating sustainability into mathematics fosters responsibility toward future generations.	44%	36%	14%	4%	2%	4.16	High
Overall Sustainability Awareness	-	-	-	-	-	**4.17**	

Table 6 presents the students' sustainability awareness, with an overall weighted mean of 4.17, interpreted as high. The top-rated item was "I became more aware of the importance of sustainable practices in daily life through mathematics lessons" (4.22), followed by "I recognized the role of mathematics in addressing environmental challenges" (4.16). These findings suggest that embedding sustainability within MMW not only increased conceptual understanding but also fostered students' environmental and social responsibility. This corroborates Leicht et al. (2020), who emphasized the transformative role of Education for Sustainable Development (ESD) in cultivating responsible citizenship. Similarly, Avila and Moreno (2021) found that integrating sustainability concepts in higher education strengthens both awareness and action-oriented skills. Moreover, UNESCO (2023) stressed that curricula that embed sustainability across disciplines encourage learners to connect knowledge with global challenges.

Taken together, the findings demonstrate that sustainability-integrated MMW instruction enhanced students' engagement, critical thinking, and sustainability awareness. High mean ratings across all domains suggest that contextualizing mathematics with sustainability themes motivates students, promotes reflective problem-solving, and nurtures socially responsible values. These results validate prior literature emphasizing the dual role of mathematics education: to develop analytical skills and to contextualize these skills in solving pressing societal issues (Wiek et al., 2019; Olsson et al., 2020). The findings support the growing consensus that embedding Education for Sustainable Development in mathematics is a powerful means of fostering 21st-century competencies.

CONCLUSION

The findings of this study revealed that embedding sustainability concepts into Mathematics in the Modern World significantly enhanced students' learning outcomes across multiple domains. Students exposed to sustainability-focused mathematical tasks demonstrated higher mathematical proficiency, improved critical thinking and problem-solving skills, stronger sustainability awareness, and greater classroom engagement compared to those taught through traditional instruction.

These results highlight the power of contextualized and interdisciplinary approaches in mathematics education. By connecting abstract concepts to real-world sustainability issues, mathematics instruction not only became more relevant but also served as a tool to foster responsible citizenship, eco-conscious values, and 21st-century competencies. This aligns with recent calls from UNESCO (2021) and Villanueva & Reyes (2024) for integrating Education for Sustainable Development (ESD) across all disciplines, including mathematics.

Therefore, sustainability education in mathematics is not merely an enhancement of content but a transformative framework that bridges numerical literacy with ethical and environmental responsibility. The study contributes to a growing body of evidence (e.g., Mendoza & Cruz, 2021; Ramos et al., 2023) advocating for pedagogical innovation that makes learning both meaningful and impactful in addressing global challenges.

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RECOMMENDATIONS

Based on the findings, the following recommendations are proposed:

For Educators:

Integrate sustainability-focused problems, case studies, and mathematical modeling activities into lessons to foster real-world application of mathematics.

Utilize project-based learning that links quantitative skills with sustainable practices, such as waste reduction, energy efficiency, and climate data analysis.

For Curriculum Developers:

Revise the Mathematics in the Modern World curriculum to explicitly include sustainability modules, ensuring alignment with **Education for Sustainable Development (ESD)** goals.

Develop instructional materials and digital resources that connect mathematics with pressing societal and environmental challenges.

For School Administrators:

Provide training programs and workshops to equip teachers with strategies for contextualizing mathematics instruction through sustainability themes.

Encourage collaboration across disciplines (e.g., mathematics, environmental science, and social studies) to reinforce integrated and holistic learning.

For Future Researchers:

Conduct longitudinal studies to examine the long-term effects of sustainability-integrated mathematics instruction on students' values and career pathways.

Explore the use of advanced methodologies such as **learning analytics and AI-driven assessments** to further measure learning outcomes and engagement in sustainability-oriented mathematics.

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