"Examining the Relationship Between Spatial Literacy and Environmental Attitude among STEM Students: Basis for Development of Instructional Framework"

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ABSTRACT

This study investigates the relationship between spatial literacy and environmental attitude among STEM students in Dinalupihan, Bataan, specifically from the different public schools within the district during the school year 2024–2025. A total of 209 students participated, selected through convenience sampling. Employing a descriptive-correlational research design, the study utilized validated questionnaires to assess spatial literacy, including spatial perception, spatial visualization, mental rotation, spatial orientation, spatial relation, and spatial communication, and environmental attitudes based on the Dominant Social Paradigm and New Ecological Paradigm frameworks. Statistical analyses were used to examine differences and relationships among variables, including the T-test, Mann-Whitney U test, Kruskal-Wallis test, and Spearman rho correlation. The results showed that environmental attitude and spatial literacy were significantly positively correlated, indicating that students with stronger spatial skills also had more pro-environmental attitudes. Grouping by sex, grade level, and school affiliation also revealed differences in environmental attitudes and spatial literacy. Based on these findings, the study suggests an instructional framework for developing environmentally aware STEM students that combines environmental education with the development of spatial literacy.

Keyword: - *Spatial Literacy, Environmental Attitude, STEM, Instructional Framework*

INTRODUCTION

The growing emphasis on Science, Technology, Engineering, and Mathematics (STEM) education has resulted in much research exploring the factors influencing students' achievement in these fields. One of these strong predictors of success in STEM education is spatial literacy (Zhou et al., 2024) [15]. According to Sorby, Veurink, and Streiner (2018) [10], spatial literacy is vital for success in STEM education, and spatial skills cultivated early in a student's educational life could significantly enhance the student's subsequent performance in mathematics, engineering, and science.

While environmental attitudes reflect individuals' awareness of environmental well-being, guiding their efforts and habits toward reducing impact (Kement et al., 2024) [7]. Furthermore, Nugrahemi (2024) [9] suggested using real-life environmental situations to teach mathematical concepts to make them relevant and interesting to the students.

Research indicates that intervention programs that are spatially focused may significantly improve environmental literacy and spatial literacy, suggesting a possible relation between the two concepts (Ayuningtyas & Irawan, 2024) [3]. However, environmental attitudes toward STEM education concerning spatial literacy remain underexplored, as supported by the following studies. Similarly, Syamsunardi et al. (2024) [11] stressed that spatial literacy enhances students' ability to comprehend and interpret spatial information that is critical in solving challenges of global concern like climate change and urbanization. Additionally, Blackley and Sheffield (2018) [4] discuss the importance of integrating spatial skills in STEM curricula to enhance understanding of ecological concepts.

The context of spatial literacy and environmental attitude is aligned with the United Nations - Sustainable Development Goals, particularly the SDG 4 (Quality Education), the SDG 11 (Sustainable Cities and Communities), the SDG 13 (Climate Action), and the SDG 15 (Life on Land). Such results from the study can be an input into educational practices and policy formulation (United Nations, 2015) [12].

Addressing the relationship between spatial literacy and environmental attitudes prepares students to effectively address global sustainability concerns, fostering responsible citizenship and academic success (Winarni et al., 2022) [14].

The research aims to examine the significant relationship between interlinking spatial literacy and environmental attitudes among STEM learners. Also, to assess the status and identify significant differences between spatial literacy and environmental attitudes among STEM learners. Moreover, to provide valuable insights to educators and policymakers by designing an instructional framework.

Theoretical Framework

The Cattell-Horn-Carroll theory, developed by Raymond B. Cattell, John L. Horn, and John B. Carroll, defines the visual processing (Gv) factor or spatial ability involves using mental images for problem-solving, generating, manipulating, and interpreting visual and spatial data, essential for navigation, puzzle solving, and complex diagram analysis. (McGrew & Wendling, 2010) [8].

The Environmental Literacy Framework by Hollweg et al. (2011) stated that environmental literacy involves understanding ecological concepts, making informed decisions, and using information to improve society and the environment, enabling individuals to engage in civic life and contribute to societal welfare (Wheaton & Ardoin, 2020) [13].

In addition, the Constructivist Learning Theory of Jean Piaget, Lev Vygotsky, and John Dewey are three constructivist psychologists with distinct viewpoints on experiential learning. Piaget emphasizes radical constructivism, whereas Vygotsky emphasizes social elements, showing that people interact with their ideas and experiences to develop knowledge; because of his belief that the individual is at the heart of the process of creating and acquiring knowledge, his conception of constructivism serves as the model for radical constructivism (EdTech Books, 2025) [6].

These three theories demonstrate the relationship between spatial skills and environmental attitudes. Spatial skills help students understand complex environmental problems, while environmental literacy inspires them to care, and active learning experiences empower them to act.

Statement of the Problem

This study explores the relationship between spatial literacy and environmental attitudes among STEM students as a basis for developing an instructional framework.

Specifically, this research intends to answer the following questions:

1. How may the profile of the STEM students be described in terms of:

   1.1. sex,

   1.2. grade level; and

1.3. school affiliation?

2. How is spatial literacy measured among STEM students in terms of:

   2.1. spatial perception,

   2.2. spatial visualization,

   2.3. mental rotation,

   2.4. spatial relation,

   2.5. spatial orientation, and

   2.6. spatial communication?

3. How are environmental attitudes measured among STEM students in terms of:

   3.1. dominant social paradigm, and

   3.2. new ecological paradigm?

4. Is there a significant difference in spatial literacy when grouped according to their profile?
5. Is there a significant difference in environmental attitude when grouped according to their profile?
6. Is there a significant relationship between spatial literacy and environmental attitudes among STEM students?
7. Based on the findings of the study, what instructional framework can be proposed?

Hypotheses

1. There is no significant difference in spatial literacy when grouped according to their profile (sex, grade level, and school affiliation).
2. There is no significant difference in environmental attitude when grouped according to their profile (sex, grade level, and school affiliation).
3. There is no significant relationship between spatial literacy and environmental attitude among STEM students.

METHODOLOGY

This study utilized a descriptive-correlational quantitative research design to describe the relationship between spatial literacy and environmental attitude. This design was appropriate for describing whether a significant relationship exists between spatial literacy and environmental attitude without controlling or manipulating these variables. As Devi et al. (2022) [5] mentioned, a descriptive-correlational design is an approach where the researcher investigates the relationships among variables without attempting to infer a cause-and-effect relationship. In this design, the researcher does not attempt to control or manipulate the situation.

The population and locale of the study are the 209 STEM students in public schools within the Dinalupihan District who officially enrolled in the school year 2024-2025. Due to uncomfortable situations restricting wider access to more randomized samples in the population, convenience sampling was used, allowing researchers to collect relevant data for the study from readily available respondents. The researchers used surveys and questionnaires to gather data. The Spatial literacy assessment (Anindyarini and Rosnawati, 2019) [2] was adopted and underwent pilot testing and reliability analysis wherein Kuder-Richardson Coefficient was used and the result shows 0.81 which means good reliability, and NEP scale (Anderson, 2012) [1] are tools that are used to test the spatial literacy and environmental attitude of the STEM students.

The mean, median, standard deviation, and interquartile range were used as descriptive statistics of the data in spatial literacy and environmental attitude. Independent T-test, Mann-Whitney U test, and Kruskal-Wallis test were used to determine the difference between spatial literacy and environmental attitude according to their profile. Spearman's rho was used to determine if there is a significant relationship between spatial literacy and environmental attitude.

RESULTS AND DISCUSSIONS

1. Demographic Profile of the Respondents

Part 1 presents the profile of the respondents in terms of sex, grade level, and school affiliation.

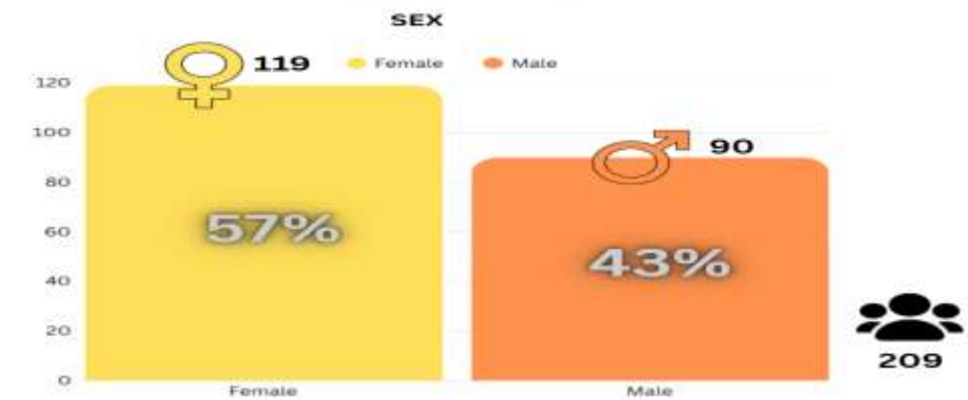


Fig. -1: Profile of the Respondents in terms of Sex

Figure 1 presents the profile of the respondents in terms of sex. As shown in the figure, out of the total 209 respondents, 119 (57%) are female, while 90 (43%) are male. This indicates that most of the respondents are female, revealing a higher participation rate of female STEM students in the study.

The distribution of respondents by sex is essential for understanding possible variations in respondents' spatial literacy and environmental attitudes. The predominance of female respondents may influence the overall results of the study, as sex may play a role in shaping students' perceptions, skills, and attitudes toward spatial and environmental concepts. Thus, the sex profile of the respondents serves as an essential consideration in analyzing the data and formulating instructional interventions that cater to the diverse needs of learners.

Fig. -2: Profile of the Respondents in terms of Grade Level

Figure 2 shows the profile of the respondents in terms of grade level. Of the total 209 respondents, 105, or 50%, are from Grade 11, while 104, or 50%, are from Grade 12. The data indicates that the respondents are almost equally distributed between the two grade levels, reflecting a balanced representation of students from both year levels.

This equal distribution is essential in ensuring that the findings of the study are not biased toward a particular grade level. The balanced representation allows for a more comprehensive understanding of students' spatial literacy and environmental attitudes across different stages of senior high school education. Furthermore, the grade level of the respondents may contribute to variations in their exposure to environmental topics and spatial skills, which are crucial considerations in the development of instructional interventions and strategies.

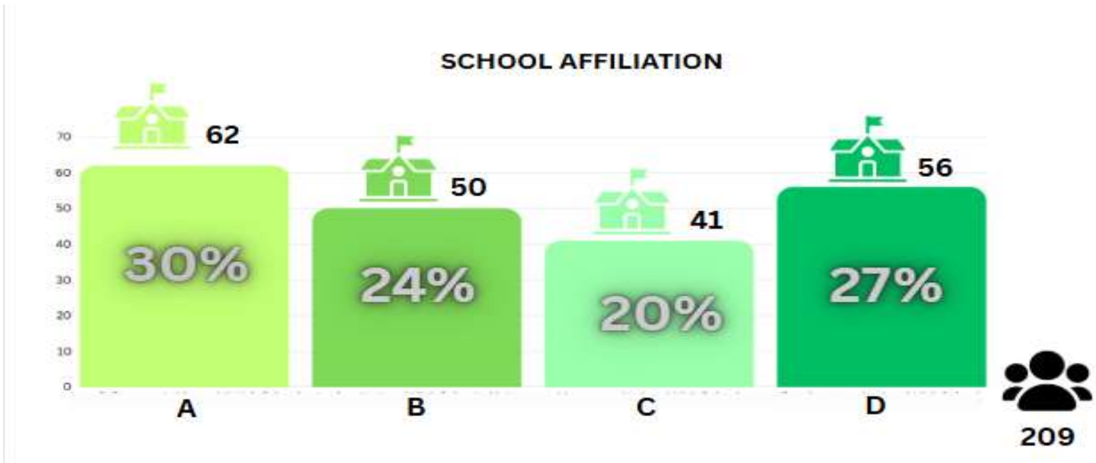


Fig. -3: Profile of the Respondents in terms of School Affiliation

According to Figure 3, which presents the profile of the respondents in terms of their school affiliation. As shown in the figure, the majority of the respondents came from School A, comprising 30% or 62 students. This is followed by School D with 27% or 56 students, School B with 24% or 50 students, and School C with 20% or 41 students.

The distribution of respondents across the four schools indicates a diverse representation of participants, allowing the study to gather varying perspectives and experiences related to spatial literacy and environmental attitude. The differences in school affiliation may reflect the distinct educational programs, environmental practices, and learning environments that could influence the students' development of spatial literacy skills and environmental attitudes. This varied representation is essential in providing comprehensive insights that can guide the development of an instructional framework that addresses the needs of students from different educational settings.

2. Spatial Literacy Scores

Description	Frequency	Mean	Median	IQR	Interpretation
Spatial Literacy Scores	209	54.02	52.94	26.47	**Novice**

Note: *(90-100)-Expert, (75-89)-Proficient, (60-74)-Developing, (Below 60)-Novice*

Table -1: Spatial Literacy Scores

As shown in Table 1 presents the spatial literacy scores of the STEM respondents. As shown in the table, the respondents obtained a mean score of 54.02 and a median score of 52.94, and an IQR of 26.47, which falls under the Novice level of interpretation. This indicates that the majority of the respondents have a limited ability to apply spatial literacy skills, such as visualizing, interpreting, and manipulating spatial information.

The results imply that there is a need to strengthen the development of spatial literacy among STEM students, as these skills are essential in understanding complex concepts in science, technology, engineering, and mathematics. The low level of spatial literacy may affect students' performance in tasks that require spatial reasoning and visualization, which are critical in STEM-related learning. Thus, the findings highlight the importance of designing an instructional framework that would enhance students' spatial literacy skills to support their academic growth and engagement in STEM education.

3. Environmental Attitude Scores

Descriptives	Frequency	Mean	Median	IQR	Interpretation
Environmental Attitude Scores	209	40.25	40	4.00	Neutral/Mixed Worldview

Note: *46-60: Strong Ecocentrism, 31-45: Neutral/Mixed Worldview, 16-30: Moderate Anthropocentrism, 15- Strong Anthropocentrism*

Table -2: Environmental Attitude Scores

Table 2 displays the environmental attitude scores of the STEM respondents. As shown in the table, the respondents obtained a mean score of 40.25 and a median score of 40, and an IQR of 4.00, which are all interpreted as *Neutral/Mixed Worldview*. This means that the students have a balanced view of the environment. They recognize the importance of taking care of nature, but at the same time, they also consider human needs and benefits.

This result suggests that while the respondents show awareness of environmental concerns, their level of commitment to environmental protection may not yet be strong. Their attitudes may vary depending on the situation, which reflects a need to further develop a deeper sense of environmental responsibility among students. Therefore, educational programs need to provide activities and lessons that promote positive environmental values and encourage students to become more mindful of their role in protecting the environment. This can help prepare them to become responsible individuals who will contribute to sustainable practices in their future careers and daily lives

4. Comparison of Spatial Literacy Scores when grouped according to their Profile

Indicator	Sex	*Median*	IQR	u	P	Decision on H_0	Interpretation
Spatial Literacy Scores	Female	50	23.53	4091	0.003	Reject	**Significant**
	Male	60.29	34.56				

Note: *At 0.05 Level of Significance*

Table -3: Test for Significant Differences in Spatial Literacy Scores when grouped according to Sex

According to Table 3, the test for significant differences in the spatial literacy scores of STEM respondents was conducted when grouped according to sex. The results revealed that male respondents obtained a higher median score of 60.29 compared to female respondents, who obtained a median score of 50. The Mann-Whitney U test was used since the data did not meet the assumption of normality ($p = .003$). The test result showed a p-value of .003, which is less than the 0.05 level of significance. Therefore, the null hypothesis was rejected, indicating that there is a significant difference in the spatial literacy scores of the respondents when grouped according to sex.

This finding suggests that male respondents performed better in spatial literacy tasks compared to female respondents. However, the computed effect size (Cohen's $d = 0.24$) indicates a small effect, meaning that although the difference is statistically significant, the magnitude of the difference between the two groups is small. This result implies that while sex may influence spatial literacy to some extent, other factors such as learning experiences, instructional strategies, and individual differences may also play important roles in developing students' spatial skills.

Note: *At 0.05 Level of Significance*

Indicator	Grade Level	*Median*	IQR	U	p	Decision on H_0	Interpretation
Spatial Literacy Scores	Grade 11	50	20.59	4623.50	0.056	Retain	**Not Significant**
	Grade 12	58.82	32.35				

Table -4: Test for Significant Differences in Spatial Literacy Scores when grouped according to Grade Level

Table 4 displays the test for significant differences in the spatial literacy scores of STEM respondents when grouped according to grade level. As shown in the table, Grade 12 respondents obtained a higher median score of 58.82 compared to the Grade 11 respondents, who had a median score of 50. The Mann-Whitney U test was used since the data violated the assumption of normality (p = .036).

The result of the test showed a p-value of .056, which is greater than the 0.05 level of significance. Thus, the null hypothesis was retained, indicating that there is no significant difference in the spatial literacy scores of the respondents when grouped according to grade level.

This finding suggests that although Grade 12 students exhibited slightly higher spatial literacy scores than Grade 11 students, the difference is not statistically significant. This implies that the grade level of the respondents does not have a strong influence on their spatial literacy skills. The result further highlights the importance of providing equal opportunities for both grade levels to engage in learning activities that enhance spatial literacy, regardless of their year level.

Indicator	School	*Median*	IQR	h	p	Decision on H_0	Interpretation
Spatial Literacy Scores	A	42.65	22.79	29.58	<.001	Reject	**Significant**
	B	55.88	33.09				
	C	50	23.53				
	D	67.65	30.15				

Note: *At 0.05 Level of Significance*

Table -5: Test for Significant Differences in Spatial Literacy Scores when grouped according to School Affiliation

As shown in Table 5, the test for significant differences in the spatial literacy scores of the respondents was conducted when grouped according to their school affiliation. As shown in the table, the respondents from School D obtained the highest median score of 67.65, followed by School B with a median score of 55.88, School C with 50, and School A with the lowest median score of 42.65.

Since the assumption of normality was not met (p = .046), the Kruskal-Wallis test was used to determine if there were significant differences among the groups. The result revealed a p-value of less than .001, which is lower than the 0.05 level of significance. Therefore, the null hypothesis was rejected, indicating a significant difference in the spatial literacy scores of the respondents across the four schools.

This result implies that the school affiliation of the respondents may influence their spatial literacy skills. The variation in the scores suggests that certain schools may have better instructional practices, learning resources, or programs that support the development of spatial literacy among STEM students. The computed effect size of 0.14 further indicates a large effect, highlighting that the differences in spatial literacy scores among schools are meaningful and worthy of consideration in designing instructional interventions.

5. Comparison of Environmental Attitude Scores when grouped according to their Profile.

Indicator	Sex	*Mean*	SD	t	p	Decision on H_0	Interpretation
Environmental Attitude Scores	Female	40.48	3.25	1.16	0.249	Retain	**Not Significant**
	Male	39.96	3.23				

Note: *At 0.05 Level of Significance*

Table -6: Test for Significant Differences in Environmental Attitude Scores when grouped according to Sex

Table 6 outlines the test for significant differences in the environmental attitude scores of the respondents when grouped according to sex. The results revealed that female respondents obtained a higher mean score (M = 40.48, SD = 3.25) compared to their male counterparts (M = 39.96, SD = 3.23).

Since the assumption of normality was met (p = .097), an independent samples t-test was used to determine if there was a significant difference between the two groups. The analysis yielded a p-value of .249, which is greater than the 0.05 level of significance. Therefore, the null hypothesis was retained, indicating that there is no significant difference in the environmental attitude scores of the respondents when grouped according to sex.

This suggests that both male and female STEM students possess relatively similar environmental attitudes. Regardless of their sex, the respondents demonstrated a neutral or mixed worldview toward the environment, as supported by their overall mean scores.

Indicator	Grade Level	*Median*	IQR	u	p	Decision on H_0	Interpretation
Environmental Attitude Scores	Grade 11	40	4	5233.50	0.603	Retain	**Not Significant**
	Grade 12	40	4				

Note: *At 0.05 Level of Significance*

Table -7: Test for Significant Differences in Environmental Attitude Scores when grouped according to Grade Level

According to Table 7, the test for significant differences in the environmental attitude scores of the respondents was conducted when grouped according to grade level. The results show that both Grade 11 and Grade 12 students obtained the same median score of 40, with an interquartile range (IQR) of 4.

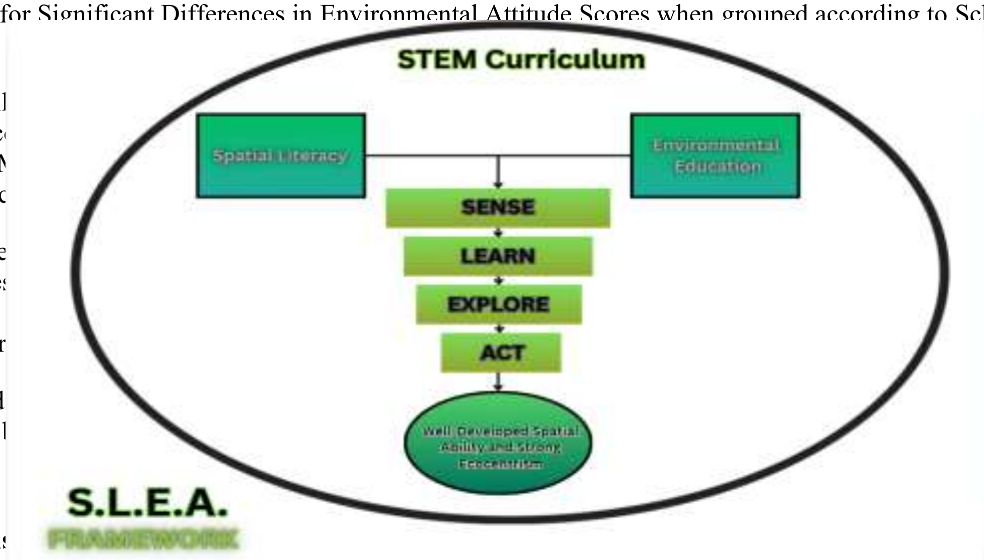
Given that the assumption of normality was not met (p = .046), the Mann-Whitney U test was employed to determine whether a significant difference exists between the two groups. The computed p-value was .603, which is higher than the 0.05 level of significance. Therefore, the null hypothesis was retained, indicating that there is no significant difference in the environmental attitude scores of the respondents when grouped according to the grade level.

This result implies that both Grade 11 and Grade 12 STEM students exhibit comparable attitudes toward the environment. Regardless of their grade level, the respondents reflected a neutral or mixed worldview in relation to environmental concerns.

Indicator	School	*Median*	IQR	h	p	Decision on H_0	Interpretation
Environmental Attitude Scores	A	39	4	22.07	<.001	Reject	**Significant**
	B	41.50	5.75				
	C	40.22	4				
	D	39	4.25				

Note: At 0.05 Level of Significance

Table -8: Test for Significant Differences in Environmental Attitude Scores when grouped according to School



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6. Relation

Variables	R	p	Decision on H_0	Interpretation
Spatial Literacy and Environmental Attitude	0.20	0.004	Reject	Significant

Note: At 0.05 Level of Significance

Table -9: Test for Significant Relationship Between Spatial Literacy and Environmental Attitude

Table 16 reveals the test for the significant relationship between spatial literacy and environmental attitude among STEM students. Since the assumption of normality was not satisfied for both spatial literacy ($p = 0.003$) and environmental attitude ($p = 0.008$), the Spearman rho correlation was utilized to assess the relationship between the two variables.

The analysis yielded a correlation coefficient of $r = 0.20$ with a p-value of 0.004, which is less than the 0.05 level of significance. Therefore, the study failed to accept the null hypothesis, indicating that there is a statistically significant relationship between spatial literacy and environmental attitude among STEM students.

This result implies that students with higher spatial literacy tend to have better environmental attitudes. However, the strength of this relationship is considered weak, as reflected in the correlation coefficient.

7. Proposed Instructional Framework

Fig. -4: Proposed Instructional Framework

The Spatial Literacy and Environmental Attitude (SLEA) instructional framework is based on the belief that spatial literacy and environmental education in STEM curricula can be integrated to help students become spatially literate and have strong ecocentrism.

In this model, integrating spatial literacy and environmental education is essential to encourage sustainable practices and insights into the spatial interaction between human actions and ecological impacts.

This framework aims to provide students with 21st-century spatial-environmental thinking. That fosters active and real-life learning, leading to civic engagement and diverse STEM professions, and promotes comprehensive thinking and understanding of the human-environment relationship.

This framework serves as a teaching guide for teachers, helping to integrate spatial literacy and environmental education. It encourages contextualized learning while cultivating environmental values and real-world problem-solving skills.

Through Sense-Learn-Explore-Act, students build spatial skills, like reading maps, analyzing land areas, or understanding where things are and why they matter. It also combines deep care for the environment, which makes learning hands-on, local, and real-world in contexts.

This also aligns with the United Nations Sustainable Development Goals (UN-SDGs), particularly SDG 4 (Quality Education)- by helping students to think deeply and learn actively, SDG 11 (Sustainable Cities and Communities)- by teaching them how places and people interact, SDG 13 (Climate Action) – by encouraging them to solve environmental problems around them, and SDG 15 (Life on Land) – by encouraging them in sustainable use and protection of terrestrial ecosystems.

CONCLUSIONS

In light of the study's results, the following conclusions were drawn.

1. Balanced representation across grade levels and schools provided diverse perspectives on spatial literacy and environmental understanding.
2. Most students encountered difficulties in applying spatial skills effectively.
3. Students highly valued nature, while also taking into account human needs.
4. Sex and school affiliation slightly influenced spatial literacy, whereas grade level showed minimal impact.
5. Male and female STEM students, as well as Grade 11 and 12 students, demonstrated relatively similar ecological attitudes, although these varied depending on their school.
6. Higher spatial literacy is associated with better ecological attitudes, though the strength of this relationship is considered weak.

RECOMMENDATIONS

Based on the findings of the study, the following recommendations are hereby presented.

1. Future research may include other possible variables that may have a salient influence on spatial literacy and environmental attitude.

2. STEM teachers may regard to develop and integrate structured intervention programs for spatial literacy within the STEM Curriculum to develop spatial literacy skills.

3. STEM teachers may organize seminars, workshops, or campaigns geared toward developing positive ecological attitudes among STEM students.

4. It may have some further analysis needed to focus on those variables dominant in this particular study, such as sex and school affiliation, to ascertain whether the trends observed remain the same.

5. To further analyze sex and grade level across the profile to inform whether these variables have contributed to differences in attitudes toward the environment.

6. Merits an investigation that looks for possible influences that might help give a fuller account of the relationship between spatial literacy and environmental attitude.

7. The educational department might consider the proposed instructional framework to be pilot tested and systematically evaluated for effectiveness to ensure that it works in enhancing both spatial literacy and environmental attitude.

8. Future research may consider employing a mixed-method approach that could yield a deeper understanding of learning spatial literacy and environmental attitude among STEM learners.

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