education sciences

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Bridging STEM Education and Sustainability: Insights from Pennsylvania Educators

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Abstract: STEM education's focus on interdisciplinary learning presents an ideal platform for integrating education for sustainability (EfS) in K–12 curricula. Understanding STEM educators' sustainability knowledge and their current incorporation of sustainability topics into STEM lessons is essential for further advancing EfS. To investigate these aspects, a mixed-methods study, involving both surveys and interviews, was conducted on STEM educators in Pennsylvania, United States. The results showed that most STEM educators surveyed had a simplified and incomplete understanding of sustainability, which aligns with the findings of international research. Despite the assumption that greater sustainability knowledge and perceived importance of EfS lead to teaching more about sustainability, no statistically meaningful correlation was found among these variables, indicating additional obstacles to integration. Watersheds, wetlands, and environmental experiences were identified as the least integrated topics in STEM curricula, suggesting a need for targeted efforts to enhance these areas.

Keywords: STEM education; sustainability education; watershed education; science education; teacher education; SDG 4: Quality Education

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Academic Editor: Neil Gordon

Received: 31 October 2024
Revised: 28 January 2025
Accepted: 20 February 2025
Published: 24 February 2025

Citation: Cordaro, J. A., Murphy, C., & Redman, E. (2025). Bridging STEM Education and Sustainability: Insights from Pennsylvania Educators. *Education Sciences*, *15*(3), 282. https://doi.org/10.3390/educsci15030282

1. Introduction

In 2015, the United Nations member states adopted the 2030 Agenda for Sustainable Development, which calls on all countries to join in a global partnership to solve the world's most pressing problems (United Nations Department of Economic and Social Affairs, 2022). Through this, the 17 Sustainable Development Goals (SDGs) were created to serve as targets for all countries to strive for. The SDGs include goals such as no poverty, zero hunger, climate action, reduced inequalities, and sustainable cities and communities—goals that would benefit the overall well-being of people globally and the planet. The United States lacks progress in most of its goals, with significant challenges to the goals of reduced inequalities and responsible consumption and production (Lynch et al., 2019; Sustainable Development Solutions Network, 2022).

Target 4.7 of the SDGs aims to ensure that all learners cultivate the knowledge and competence to promote sustainable development by 2030 (United Nations Department of Economic and Social Affairs, 2022). Education for sustainability (EfS[1]) has emerged as a guide for instigating a shift in educational systems that keeps the well-being of people, the planet, and other beings at the frontline (Nolet, 2009; Santone, 2003; Sterling, 2010). EfS focuses on the development of competencies such as critical thinking, systems thinking, interpersonal, normative, strategic, and anticipatory, all of which are required to change the current paradigm regarding human relationships with other beings and the Earth (Abrom et al., 2021; Corres et al., 2020; Redman & Wiek, 2021; Wiek & Redman, 2022; Nolet, 2015; UNESCO, 2017; Wiek et al., 2011).

Science, technology, engineering, and mathematics (STEM) education provides an ideal space for exploring the SDGs and targeting key sustainability competencies, with research in this area being a new but growing field (Lathifah et al., 2024). STEM education is "the integration of a number of conceptual, procedural, and attitudinal content via a group of STEM skills for the application of ideas or the solving of interdisciplinary problems in real contexts" (Martin-Paez et al., 2019, p. 803). It is a methodology that integrates the content areas in the acronym, allowing topics to be explored and applied in a real-world manner by disassembling the typical silos of educational content (Bybee, 2013; Martin-Paez et al., 2019; Vasquez et al., 2013). Similar to EfS, STEM education focuses on the development of competencies like systems thinking, critical thinking, collaboration, and strategic thinking (Cordaro & Murphy, 2025; Martin-Paez et al., 2019; McLoughlin et al., 2020).

Through real-world problem solving, the STEM education classroom can provide students with opportunities to examine the SDGs and engage in EfS (Fakhrudin et al., 2021; Nguyen et al., 2020). For example, a STEM lesson on SDG 2 (zero hunger) could explore topics like agriculture, food systems, and indigenous practices, using inquiry-based learning to find solutions. Some STEM educators naturally integrate the SDGs, as seen in a study of Vietnamese teachers who initiated projects on local and global issues like pollution and sustainable consumption (Nguyen et al., 2020). While the potential for integrating the SDGs and sustainability in STEM is clear, there is limited evidence of its widespread practice in U.S. K–12 schools.

Both EfS and STEM education face similar challenges. Studies show that while EfS is recognized as important, educators often have a limited understanding of sustainability and lack the self-efficacy to teach it effectively (Agirreazkuenaga, 2019; Bezeljak et al., 2020; Maidou et al., 2019; Murphy et al., 2020; Santone et al., 2014; Timm & Barth, 2020; Walker et al., 2017). Some studies have found differences in EfS knowledge based on the grade level taught, with high school teachers demonstrating limited knowledge of sustainability-related topics (Smaniotto et al., 2022), although the reasons remain unclear. Pre-service educators also show strong intent to teach EfS but often confuse it with environmental education due to limited knowledge (Stössel et al., 2021). Similarly, educators often have different ideas of what STEM education comprises, leading to a lack of educator confidence in its implementation (Aguilera et al., 2021). Furthermore, both STEM and EfS educators report barriers such as time constraints, exam-focused curricula, and the complexity of interdisciplinary content as barriers to implementation (Munasi & Msezane, 2024; Stössel et al., 2021; Timm & Barth, 2020; Walker et al., 2017).

Given that educators' knowledge and beliefs shape their teaching practices, understanding their views on EfS is a critical first step for its successful integration and implementation (Andic & Vorkapic, 2017). Therefore, this study explores the current state of STEM educators' knowledge and beliefs regarding EfS.

Existing models for engaging students in EfS through STEM education have shown promising results regarding students' understanding of environmental issues and competencies (Alkair et al., 2023). However, there needs to be more evidence of widespread implementation of these methods to develop learners globally who hold the knowledge, skills, and abilities necessary to realize a sustainable future and enter sustainability-related fields (National Academies of Sciences, Engineering, and Medicine, 2020; UNESCO, 2020). This study seeks to address gaps in the literature that hinder our understanding of whether and how EfS is integrated into K–12 STEM education within the local context of Pennsylvania.

1.1. Significance of This Study

The key to achieving target 4.7 of the SDGs is to first ensure that educators are competent and confident in EfS instruction. While some nations, such as Spain, France, Brazil, India, and China, have successfully mainstreamed education for sustainable development into teacher education programs, the United States and numerous other nations have either not mainstreamed EfS in teacher education or lack data in this area (United Nations Department of Economic and Social Affairs, 2023). Exploring how STEM educators use sustainability topics in their classroom, what barriers are hindering the integration of these topics, and STEM educators' knowledge of sustainability will provide a starting place to further develop strategies for professional learning.

This study was conducted in the U.S. state of Pennsylvania, where new academic science standards were implemented in 2024. These standards have three branches: science, technology and engineering, and environmental literacy and sustainability (Pennsylvania Department of Education, 2023). These standards, frequently referred to by their acronym (STEELS), are designed to use inquiry-based problem solving, critical thinking, and exploration of science phenomena in an intersectional manner (Pennsylvania Department of Education, 2023). The content of the environmental literacy and sustainability section of the standards is a new addition that may be unfamiliar to K–12 science teachers, as there was not a strong focus on this area in previous versions of the standards. Understanding educators' knowledge of sustainability and where it provides context in the current classroom will provide a snapshot of current practices, identify gaps, and allow for targeted support for seamless integration of the STEELS standards in the future.

1.2. Research Questions

As a first step to strengthening EfS in the K–12 classroom, it is important to gain insight into sustainability topics that are currently being integrated, educators' perceived importance of these topics, what topics are currently being taught, and what barriers are hindering integration. Doing so can establish a baseline for future pre-service and in-service educator training and address areas of weakness. Additionally, determining what knowledge STEM educators have about sustainability will help determine how they will teach it. Therefore, this study aimed to examine K–12 STEM educators' sustainability knowledge and explore how they use sustainability contexts in STEM education. The primary research question that guided this study was "To what extent do K–12 STEM educators in Pennsylvania use sustainability topics as a context for K-12 STEM lessons?" The secondary research question aimed to examine the factors that support or hinder the integration of sustainability topics in STEM education: "What factors influence teachers' integration (or lack thereof) of sustainability concepts into their curriculum and classroom practices?"

2. Materials and Methods

2.1. Methodology and Research Design

In this study, a mixed-methods design was chosen to explore the research question by gathering data via an online survey and interviews to gain insight into the current status of sustainability contexts used within the STEM classroom. A convergent parallel mixed-methods approach was used to determine the extent to which STEM educators use sustainability topics in their learning and instruction. The qualitative and quantitative data were collected in a single phase, and then they were merged and analyzed (Creswell & Creswell, 2018).

2.2. Theoretical Framework

This research was conducted using a post-positivist lens, which explores the cause-and-effect relationships between variables (Creswell & Creswell, 2018). Post-positivism acknowledges no universal truth but instead explores various complex understandings by studying them from multiple angles using multiple methods (Panhwar et al., 2017; Ryan, 2006). This approach was used to explore the subjective reality of STEM educators in Pennsylvania, leading to an understanding of the current knowledge, skills, and attitudes regarding EfS among STEM educators.

The Sustainability Education Framework for Teachers (SEFT) provides the theoretical foundation for this research. By focusing on four key competencies—systems thinking, futures thinking, values thinking, and strategic thinking—the SEFT enhances educators' understanding of sustainability's complexities, its solution-oriented approach, and its significance in their roles as both educators and citizens (Warren et al., 2014). According to Warren and colleagues, mastering these competencies empowers educators to teach sustainability effectively and engage with society critically and strategically (2014).

2.3. Data Collection

The methods used for collecting data in this study were surveys and interviews. The development of each method will be explained in detail below.

Survey: An online survey created through Qualtrics was used to collect participants' data at their convenience. Using a combination of Likert-style questions, closed-ended responses, and open-ended responses, the survey aimed to understand STEM educators' sustainability knowledge, their perceived importance of EfS, whether they use sustainability contexts in the classroom, and their reasons for using or not using these contexts. The survey draft was piloted with a small group of educators to ensure clarity and relevance, enhancing its validity and reliability. Table 1 outlines the constructs measured in each section of the survey, along with a description of the questions, each of which will be described in detail below. A complete version of the survey sections described below is provided in Appendix A.

Table 1. Overview of the survey instrument.

Construct	Description of Questions
Sustainability content knowledge	Open-ended self-reported definition of sustainability. Scored using rubric developed by Brandt et al. (2021).
Perceived importance of EfS in the STEM classroom	Perceived importance of EfS scale (six 5-point Likert-scale items). Modified from Tomas et al. (2017).
Use of sustainability as a context in the STEM classroom	Eight closed-ended yes/no questions listing sustainability topics. Topics are derived from the Pennsylvania Department of Education's STEELS standards (2023).
Justification for the use or lack of sustainability as a context in the STEM classroom	Multiple-choice selection of why educators may or may not teach a topic (e.g., lack of time, not in curriculum, student interest, etc.).

The construct of sustainability content knowledge was assessed through an open-ended text entry question asking for the participants' definition of sustainability. This assessment method has been used in prior studies and was selected for its ease of use (Agirreazkuenaga, 2019; Bezeljak et al., 2020; Brandt et al., 2019, 2021). The definitions were analyzed using a rubric developed by Brandt and colleagues (2021), which focuses on two key aspects of sustainability: the multidimensional perspective (i.e., acknowledging sustainability beyond environmental concerns) and the multi-generational perspective (i.e., considering both current and future generations.)

To measure the perceived importance of EfS in the STEM education classroom, a modified version of the perceived relevance of EfS scale was used (Tomas et al., 2017). The modifications did not remove meaning from the questions but instead tailored them to in-service K–12 educators and included minor language adjustments. An additional question was added—"I actively seek to integrate sustainability topics in my teaching"—to explore the participants' thoughts on EfS integration.

To determine the use of sustainability contexts in the STEM education classroom, participants were presented with a set of eight topics associated with environmental literacy and sustainability. The participants were asked to indicate "yes" or "no" to using each topic as a context in their classroom in the past two years. The targeted topics were based on the environmental literacy and sustainability domain of the Pennsylvania Department of Education's STEELS standards that were adopted in 2024 (Pennsylvania Department of Education, 2023).

Next, the participants were prompted to provide reasons for their selection or rejection of the sustainability topics presented in the previous section. They could choose from a list of reasons why they did (e.g., "it is a part of the curriculum", "this context is of interest to me") or did not teach that topic (e.g., "I don't feel knowledgeable enough to instruct with this context", "it is not a part of the curriculum"). Participants were able to select multiple reasons for each topic, as well as to enter another reason if an accurate option was not provided.

Descriptive and inferential statistics were used to analyze the survey data. Descriptive statistics allowed for a clear summary of the participants and the extent to which they use sustainability in their classroom, while inferential statistics allowed for drawing conclusions and generalizations about STEM educators in Pennsylvania (Creswell & Creswell, 2018; Ravid, 2020).

Interview protocol: To gather more detailed information about STEM educators' use of sustainability topics in their classroom and their views on EfS, virtual semi-structured interviews were conducted. The interviews first asked the participants about their background, work history, academic history, knowledge of STEM education, and current teaching position. The participants were then asked to define sustainability in their own words and elaborate on their definitions. Next, the interviewer gathered details on whether the participants thought sustainability was relevant in the STEM classroom. Lastly, the participants were shown a slide with the eight topics presented in the survey and asked to discuss whether they had integrated each topic into their lessons at any point during the last two years, and to elaborate on the experience.

The interviews were recorded, transcribed verbatim, and analyzed using Dedoose, a qualitative coding software platform. Inductive thematic analysis derived several themes, including the educators' knowledge of sustainability, perceived importance of EfS, experiences using sustainability topics in the STEM classroom, and barriers to using sustainability topics in the STEM classroom (Braun & Clarke, 2006). These data were triangulated with quantitative data obtained from the interviews to provide the findings of this research.

2.4. Participants

This study targeted K–12 STEM educators statewide in Pennsylvania. Since the term "STEM educator" remains loosely defined in Pennsylvania, any full-time K–12 educator who taught any of the science branches of the current Pennsylvania Department of Education's academic standards was eligible to participate. Voluntary convenience and snowball sampling methods were used by distributing a link to the survey via email to members of the Pennsylvania Statewide STEM Ecosystem (PSSE), comprising over 800 STEM-related stakeholders, including educators, administrators, and policymakers (Pennsylvania Statewide STEM Ecosystem, 2023). An email was sent to ecosystem members encouraging eligible members to participate and share the survey with their peers.

A total of 104 educators responded to the survey; 7 respondents indicated that they did not meet the eligibility requirements, 17 opened the survey but did not answer any questions, and 14 had incomplete submissions, narrowing down the eligible responses to 68. Due to 6 respondents indicating that they taught across broad grade ranges (K–12), analyzing their results posed challenges, leading to their exclusion from the analysis. Consequently, the research focused on analyzing 62 complete responses. A summary of the demographic information regarding the participants can be found in Table 2 and is outlined below.

Table 2. Cross-tabulation: grades taught and years in education.

	Years in Education			
	10 Years or Less	**11 to 20 Years**	**21 or More Years**	**Total**
Elementary (grades K–5)	4	9	4	17
Middle school (grades 6–8)	9	5	3	17
High school (grades 9–12)	7	13	8	28
Total	20	27	15	62

A total of 17 educators taught elementary grade levels, i.e., kindergarten (K) through grade 5. Another 17 taught middle school (grades 6 through 8), while 28 taught high school (grades 9 through 12). The total years of teaching were evenly distributed, with 20 having 1 to 10 years of teaching experience, 27 having 11 to 20 years of teaching experience, and 15 having 21 years or more of teaching experience. This indicates that the results represent educators with a range of teaching experiences.

Eleven survey respondents showed interest in taking part in an optional virtual interview to provide further details about their responses. Of those eleven, three did not respond to emails to schedule the interview, and one was deemed ineligible due to having a close friendship with the primary researcher, creating potential bias. Seven educators were selected for a virtual interview, and for confidential purposes their names will remain undisclosed. These educators included two from the elementary level, two from middle school, and two from high school. One educator taught middle school and high school, teaching a required 7th-grade STEM course and a STEM elective offered to grades 9–12. Four of these educators had less than ten years of teaching experience, while three had between 11 and 20 years. Various subjects were taught, including elementary science, elementary gifted support, STEM or STEAM, biology, environmental biology, and carpentry. A summary of their demographic information can be found in Table 3.

Table 3. Profile of educators interviewed.

Interview	Subject(s) Taught	Grades Taught	Years in Education
1	STEAM (elective) and gifted support (elective)	Middle school	10 or less years
2	STEM (required for 7th grade, elective for grades 9–12)	Middle school and high school	11 to 20 years

Table 3. *Cont.*

Interview	Subject(s) Taught	Grades Taught	Years in Education
3	Environmental biology	High school	11 to 20 years
4	Carpentry	High school	10 or less years
5	Gifted support	Elementary	10 or less years
6	Biology	High school	11 to 20 years
7	Science	Elementary	10 or less years

2.5. Reliability and Validity

Efforts were taken to ensure internal consistency among the Likert-scale items and inter-rater reliability of the scored sustainability responses. Cronbach's alpha for the seven questions measuring the perceived importance of EfS was .752, showing an acceptable level of internal consistency. Inter-rater reliability was assessed by having two additional raters score a sample of the responses aimed at measuring sustainability knowledge. A single-measure intraclass correlation coefficient for the construct of sustainability knowledge was .864, indicating a high level of agreement between the raters. This value indicates that it is highly likely that the scores given by the primary researcher are consistent with the scores that would be given by the other two raters on all responses. Furthermore, care was taken to ensure that the interviewed educators accurately represented the entire sample. The educators selected for interviews taught grade levels proportionate to those of the educators surveyed overall.

3. Findings

The findings from this study draw on the analysis of the online survey and seven interviews. They are organized into the main constructs analyzed through the data analysis: STEM educators' sustainability knowledge, perceived importance of sustainability in education, most common sustainability topics taught, and areas for improvement.

3.1. STEM Educators' Sustainability Knowledge

The survey results indicate that STEM educators have limited knowledge of sustainability, as determined by the scoring of their open-ended definitions of sustainability. The scores for each rubric domain were added to calculate a total, which was then averaged by dividing by the number of participants to obtain a mean score. A summary of the results can be found in Table 4, which depicts the results of the scored responses for the total population sample.

Table 4. Understanding of sustainability.

	N	M	SD
Overall sustainability definition (0–5): time perspective + dimension orientation	62	.87	1.079
Time perspective (0–3): 0 = no time perspective, 1 = future perspective, 2 = intergenerational perspective, 3 = intergenerational and intra-generational perspective	62	.42	.759
Dimension orientation (0–2): 0 = no dimensions included, 1 = one-dimensional perspective, 2 = multidimensional perspective	62	.44	.617

The educators' sustainability knowledge was measured on a five-point scale, with a mean score of .87 and a standard deviation of 1.079, indicating a low level of sustainability knowledge. None of the educators achieved the maximum score. Of the respondents, 71% did not mention a time perspective in their responses, indicating a minimal understanding of inter- and intra-generational outlooks. Additionally, 63% did not consider any sustainability dimensions (environmental, social, or economic), and those who did focused primarily on the environment. These results indicate a narrow understanding of sustainability's multi-faceted nature.

The results of the sustainability definition scoring revealed that the educators who taught higher grades tended to have more knowledge of sustainability than those teaching lower grades. Table 5 and Figure 1 display the means by grade level: elementary educators demonstrated the lowest level of understanding of sustainability (M = .35, SD = .606), followed by middle school educators (M = .59, SD = 1.064), and high school educators (M = 1.36, SD = 1.129). The data met the assumptions for parametric tests, including normality and homogeneity of variance, with Levene's test showing no significant variance differences for knowledge of sustainability ($F(2, 59) = 2.967$, $p = .059$). A one-way ANOVA revealed a statistically significant difference in sustainability scores across grade levels ($F(2, 59) = 6.331$, $p = .003$) (Creswell & Creswell, 2018), and Tukey's HSD test for multiple comparisons found that the mean sustainability definition score was significantly different between elementary educators and high school educators ($p = .005$, 95% C.I. = −1.74, −.27), as well as between middle school educators and high school educators ($p = .039$. 95% C.I. = −1.50, −.03). There was no statistically significant difference in the mean sustainability definition scores between elementary educators and middle school educators ($p = .771$).

Table 5. Means, standard deviations, and one-way ANOVAs by grade level.

Measure	Grades K-5		Grades 6–8		Grades 9–12		F(2,59)	η^2
	M	*SD*	*M*	*SD*	*M*	*SD*		
Sustainability knowledge (maximum possible score = 5)	.35	.606	.59	1.064	1.36	1.129	6.331	**.003** **
Perceived relevance of EfS (maximum possible score = 30)	19.88	4.675	20.82	4.475	22.00	3.377	1.483	.235
Sustainability topics used as a context in STEM lessons (maximum possible score = 8)	3.94	2.883	3.94	2.926	5.00	2.465	1.170	.317

** $p < .01$.

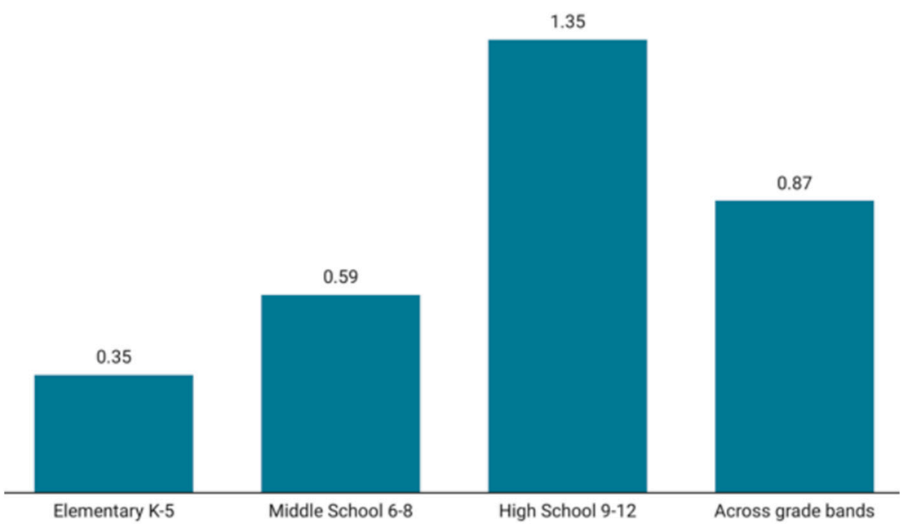

Figure 1. Mean sustainability scores by grade band taught.

Statistical analysis was conducted to investigate the relationships between educators' sustainability knowledge, perceived importance, and integration of sustainability concepts into teaching. Since the data met the assumptions for parametric tests, a Pearson correlation was calculated to determine whether correlations were present (Creswell & Creswell, 2018). Using a threshold p-value of .05, the results revealed no statistically significant relationship between an educator's sustainability definition scores and their perceived importance of education for sustainability (r (60) = .077, p = .552). Furthermore, there was no correlation between an educator's sustainability definition score and their integration of sustainability topics into their lessons (r (60) = .103, p = .428). These results suggest that factors beyond perceived importance and sustainability knowledge motivate educators to include sustainability topics in STEM content.

Analysis of the educators' open-ended responses about their understanding of "sustainability" revealed common themes. Approximately 60% perceived sustainability as maintaining the status quo of a situation, while around 18% considered it to be about improving conditions for the future. While 39% of respondents referred to environmental systems (e.g., "doing things in a way that is healthy for the environment over a long term"), only 7% considered economic systems (e.g., "the ability to keep an initiative or program running after the initial start-up",), and 3% mentioned social systems or people (e.g., table "When you consider the equitable balance of people, planet, profit"). Mechanistic viewpoints were also found across several responses, with a theme of effectiveness, rates, and products (e.g., "to keep something working or in effective use for as long as possible"). These results suggest that the educators surveyed hold simplified views of sustainability, with little consideration for its multidimensional and temporal perspectives, and with a tendency to focus on maintaining systems without outside influence.

3.2. Perceived Importance of Sustainability in STEM Education

The findings of this study revealed that the higher the grade level an educator taught, the higher their perceived importance of EfS. Out of a maximum of 30, the mean score for elementary, middle school, and high school educators was 19.88, 20.82, and 22.00, respectively, as shown in Table 5. The data met the assumptions for parametric tests, including normality and homogeneity of variance. Levene's test indicated that the variances for the perceived importance of sustainability in STEM were not statistically significant ($F(2, 59) = .192$, p = .826), confirming that one-way ANOVA is an appropriate test for comparing means. Although there was a clear difference in scores across these grade levels, a one-way ANOVA revealed that these results were not statistically significant ($F(2, 59) = 1.1483$, p = .235).

The findings revealed a possible relationship between educators' belief in their role in solving environmental problems through education and their use of sustainability as a context for their lessons. A two-tailed Pearson correlation revealed no significant relationship between educators' perceived importance of EfS and their integration of sustainability topics into lessons (r (60) = .211, p = .100). However, the analysis uncovered a statistically significant positive correlation between the response to the question "teachers play an important role in solving environmental problems through education" and their use of sustainability as a context in lessons (r (60) = .297, p = .019). Additionally, a statistically significant positive correlation was also found between educators who indicated that they actively seek to integrate EfS into their lessons and their actual integration of these topics (r (60) = .257, p = .044). This suggests that educators who believe they can help solve sustainability problems through education are more likely to include sustainability topics in STEM education.

Qualitative interview data revealed that all educators interviewed agreed that it is critical that sustainability is integrated into the STEM classroom. An example quote from an interviewee echoed this thought (Table 6, quote 1a), and other example quotes from the educators interviewed can be found in Table 6. Many interviewees also noted that while environmental educators focus on identifying problems, STEM educators focus on designing solutions (Table 6, quote 1b), highlighting the role of STEM in sustainability solutions.

Table 6. Educator sample responses from interviews.

Concept	Example Evidence from Interview
Importance of sustainability in the STEM classroom	Quote 1a: "My purpose is to teach them how to think so that they can be problem solvers, that they are aware of issues out there in the world, in their community, and giving them a process where they can find problems and design solutions for them". Quote 1b: "It is important for the STEM teacher to teach sustainability because their job is going to be to find the solution".
STEM educator preference to focus on local issues	Quote 2: "I actually prefer to focus on that. I would rather my students learn something about an animal that they're going to see outside than a polar bear".
STEM educator's reasons for using sustainability topics as a context for lessons	Quote 3: "It's tying knowledge and learning into the real world. like everyday life, which I think is important, and I think it gets the kids more engaged. If they realize if they can tie it to their real life instead of like, okay, I have to think about this for 40 min, and then I can stop".
Focus on watersheds and wetlands	Quote 4a: "I put it in there because I feel like they need to know what a watershed is and how pollution happens. And then we talk about estuaries, and I reference the Chesapeake Bay quite a lot and fertilizer impact, farmland impact, pet waste. . . you know because most of them have pets and then farmland because obviously in Pennsylvania there's a lot of cows. . . and you know a lot of crops being grown and all of that ends up in the Chesapeake Bay". Quote 4b: "I was a wetland biologist with engineering companies. I did environmental planning for local municipalities, things like that. So that's definitely my area of interest. So I make sure that we do a lot with that".
Desire to focus more on sustainability topics	Quote 5a: "So many topics, we have so many topics to cover. . .And you're a tested subject that they kind of care about, but really don't. So, it's like there'd be more pressure. But at least there would be more resources behind it". Quote 5b: "I wish I felt like I had more time to spend on this kind of things. I feel like, those are a lot more tangible applications of science than some of the things we spend our time on".

When asked to define sustainability, the educators' responses aligned with the survey findings. Those with a deeper understanding of sustainability valued its importance and actively incorporated it into their teaching. However, challenges to fully integrating sustainability topics still exist, which will be discussed in a subsequent section.

3.3. Most Common Sustainability Topics Taught and Factors Influencing Educators

Determining which of the presented sustainability topics are currently taught in Pennsylvania schools can show areas of strength in implementing the environmental literacy and sustainability branch of the STEELS standards. Of the eight sustainability topics presented, agriculture and food systems and local environmental issues' impact on larger systems were reported as the most taught topics among the educators surveyed (n = 38). Table 7 presents a grade-level breakdown of each topic taught, along with the total number of educators teaching each specific topic. The findings indicate that the high school educators (grades 9–12) appeared to cover these sustainability topics more frequently compared to the elementary (grades K–5) and the middle school (grades 6–8) educators. The interviews revealed similar findings, with six of the seven educators indicating that they taught about agriculture and food systems to some degree, and all indicating that they teach about how local environmental issues impact larger systems. Two educators stated that local environmental issues were their primary focus in classroom projects and learning experiences. Examples of local issues included school-based stormwater projects, designing solutions to enhance community walkability, and student-led campaigns to reduce straw usage at local restaurants. The educators indicated that they believe this content is more relatable to the students (Table 6, quote 2).

Table 7. Summary of sustainability topics taught by grade level.

	Agricultural and Food Systems	**Effects of Social and Cultural Beliefs on the Environment**	**Watersheds and Wetlands**	**Local Environmental Issues' Impact on Larger Systems**	**Environmental Experiences**	**Evaluation of Environmental Solutions**	**Developing Solutions to Promote Environmental Stewardship**	**Inequitable Effects of Environmental Hazards on Populations**
Grades K–5	9 (53%)	8 (47%)	8 (47%)	10 (59%)	6 (35%)	6 (35%)	12 (71%)	7 (41%)
Grades 6–8	10 (59%)	9 (53%)	5 (29%)	11 (65%)	7 (41%)	10 (59%)	8 (47%)	8 (47%)
Grades 9–12	19 (68%)	17 (61%)	14 (50%)	17 (61%)	16 (57%)	21 (75%)	17 (61%)	19(68%)
Total of all educators	38 (61%)	34 (54%)	27 (43%)	38 (61%)	29 (47%)	37 (59%)	37 (59%)	34 (54%)

When asking educators the reasons why they teach any of the eight sustainability topics presented, the main reason provided was that they found the information relevant to their students (n = 41), followed closely by personal interest in the topic (n = 40). Other common reasons provided by the educators included connections to their academic standards (n = 39) and student interest in the topic (n = 34). Figure 2 shows the number of responses for each selection. The interviews revealed similar reasons for choosing sustainability topics, where the interviewees indicated connections to academic standards, student-led learning, and educators' perceived relevance and personal interest as common reasons why they engaged students in particular topics (Table 6, quote 3).

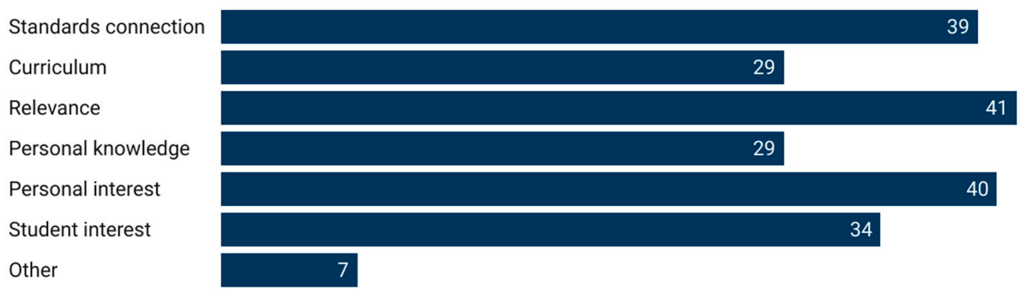

Figure 2. Total of educators' reasons why they teach sustainability topics.

3.4. Areas for Improvement and Factors Influencing Educators

The data were also analyzed to identify the sustainability topics that were taught the least. Table 7 depicts the number of educators who indicated that they had taught a sustainability topic in the past two years. The results revealed that watersheds and wetlands were the topics most infrequently taught, with less than half (n = 27) of respondents indicating that they teach about this topic. Educators of grades 6–8 showed particularly low coverage, with only 5 out of 17 including this topic. The main reasons cited for the omission of the presented topics were curriculum constraints (n = 33), lack of time (n = 24), lack of alignment with academic standards (n = 19), and gaps in personal knowledge (n = 11). Further details on why educators did not teach the presented sustainability topics can be found in Figure 3, which details other reasons cited by the educators for omitting these topics.

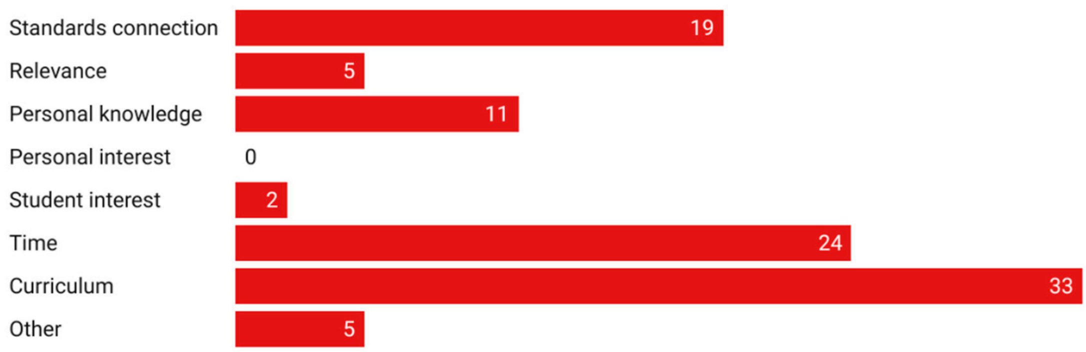

Figure 3. Educators' reasons why they did not teach sustainability topics.

The interviews revealed that four of the seven educators taught about watersheds and wetlands and emphasized their relevance to the curriculum and students' lives (Table 6, quote 4a), with personal knowledge emerging as a key theme (Table 6, quote 4b).

Environmental experiences, like field trips and community investigations, were the second least taught topic among the surveyed educators (n = 29). These experiences were particularly limited at the elementary and middle school levels, with only 35% of grades K–5 and 41% of grades 6–8 engaging students in environmental experiences. The interviews confirmed that high school educators engage more in environmental experiences than those teaching younger grades, although these experiences are not available to all students. For example, in a Pittsburgh biology class, about 30 students participate in annual conservation projects, leaving many without such opportunities. These findings indicate that while some educators provide opportunities for environmental experiences, they are often limited to a small number of students and more frequently offered to high school students.

The survey participants cited curriculum constraints as the primary reason for not teaching certain sustainability topics (n = 36), followed by lack of time (n = 27), connection to academic standards (n = 19), and personal knowledge (n = 12). The interviews confirmed these barriers, with educators noting time constraints, lack of connections to standards, and missing topics in the curriculum. The educators expressed a desire for more time to cover sustainability topics due to their real-world relevance (Table 6, quote 5a), although state-standardized science assessments took priority (Table 6, quote 5b).

4. Discussion

The SEFT framework views sustainability as a form of literacy that is equally important to education as language or math, with sustainability competencies being vital for teacher education and lesson development (Warren et al., 2014). This study's findings suggest that STEM educators in Pennsylvania have limited sustainability literacy and would benefit from opportunities to enhance their sustainability knowledge. The findings of this study align with previous research showing that educators tend to hold simplified views of sustainability and lack self-efficacy in teaching this area (Agirreazkuenaga, 2019; Bezeljak et al., 2020; Maidou et al., 2019; Murphy et al., 2020; Santone et al., 2014; Timm & Barth, 2020; Walker et al., 2017). The educators who participated in this study demonstrated limited systems thinking, with few responses reflecting the multidimensional nature of sustainability. The low number of educators considering temporal dimensions suggests a limited competence in futures thinking (inter- and intra-generational perspectives), contrasting with a study of German pre-service educators, which highlighted temporal perspectives as central to EfS (Stössel et al., 2021). This contradiction in research results may indicate different background knowledge regarding sustainability and its competencies, and this is an area that can be explored in future research.

Our findings also support previous research that asserts that STEM education often lacks a socioscientific and sociocultural perspective (Ariza et al., 2021; Zeidler, 2016). However, about half of the educators reported teaching the interdisciplinary topics presented, which has been a barrier for educators in previous studies (Munasi & Msezane, 2024). The scope of this study does not clarify whether they considered the multidimensional nature of these topics in their instruction or whether they focused solely on environmental aspects. Without the socioscientific and sociocultural perspectives on complex, interdisciplinary STEM issues, educators may overlook important complexities, leading to one-dimensional lessons that do not consider all relevant factors.

The cause of this difference, with educators in higher grades possessing greater sustainability knowledge than those who teach lower grades, is not yet known, but a potential factor is the fact that middle and high school educators typically take more content-focused courses in the sciences, which may increase their sustainability knowledge. These results contradict those of an Italian study (Smaniotto et al., 2022), which relied on self-reported knowledge, whereas the present study used alternative methods. The difference between self-reported and scored responses may explain this discrepancy and warrants further exploration.

The SEFT framework views sustainability as a literacy that is as essential to education as language or math literacy, with specific competencies outlined in the framework. It also suggests that sustainability competencies should be integrated into teacher education programs and considered during lesson development. This study found that educators of higher grade levels perceived EfS as more relevant and possessed greater sustainability knowledge. These findings suggest that sustainability literacy is more common among higher-grade educators, likely due to more content-specific education in pre-service teacher programs. This raises the question of whether the competencies needed for sustainability literacy are included in the coursework for pre-service secondary STEM educators. Although existing studies examine ESD content and competencies throughout teacher education programs, no studies have been found that directly compare the development of competencies needed for sustainability literacy across different grade levels, and this could be an area for future research (Imara & Altinay, 2021; Potter-Nelson, 2020; Raman et al., 2022). Additionally, these findings raise the following question: Does a higher level of science content knowledge correlate with more positive perceptions of sustainability's relevance and increased sustainability literacy?

Contrary to the assumption that greater sustainability knowledge and perceived importance lead to more integration of sustainability in lessons, no significant relationship was found, suggesting additional barriers to integration. Other authors have suggested that declarative knowledge regarding sustainability is insufficient for motivating participation in sustainability. This study reinforces that finding, indicating that we must go beyond declarative knowledge if we hope to foster education for sustainability (Redman & Redman, 2014). Elementary educators may prioritize core subjects like reading and math, potentially limiting professional learning in science pedagogy. Similar challenges were noted in previous studies, including time constraints, structural barriers, low knowledge levels, and a restrictive school environment (Munasi & Msezane, 2024; Stössel et al., 2021; Timm & Barth, 2020; Walker et al., 2017). Addressing these challenges requires structural changes to remove the typical siloed structure of classes, allowing for more interdisciplinary and transdisciplinary lessons. This study indicates that higher-grade educators teach sustainability topics more frequently, but it is unclear whether they adopt a multidimensional perspective. In contrast, elementary educators teach fewer sustainability topics but have greater potential for interdisciplinary, multidimensional lessons due to their typical instruction across multiple content areas. Future research could explore the depth to which they consider the multidimensional nature of sustainability topics in their lessons.

4.1. Opportunities in Pennsylvania

In Pennsylvania, where this study was conducted, a positive development regarding the integration of sustainability content has been the adoption of the STEELS academic standards, which incorporate science, technology, engineering, environmental literacy, and sustainability. It is anticipated that this conceptual shift in standards will connect disciplinary core ideas, science and engineering practices, and crosscutting concepts (Pennsylvania Department of Education, 2023). Consequently, K–12 educators will now be tasked with teaching the interdisciplinary sustainability concepts highlighted in this study, such as agricultural and food systems, environmental justice, and watersheds. These standards will also be a part of standardized assessments in grades five and eight, helping prioritize this content across grade levels and diminishing the barriers currently inhibiting the integration of sustainability.

Although this change will help merge EfS with STEM education, the findings of this study and others suggest that significant efforts will be required to accomplish the task of educating for sustainability. Concerns arise from this study regarding educators' readiness to teach these topics, particularly in elementary and middle school grades, where standardized testing on this content occurs. This could leave educators unprepared to address the environmental literacy and sustainability components of the new standards, hindering students' development of a scientific mindset. Training in EfS is crucial for all science educators, especially those in lower grades, to facilitate this transition. District administrators should prioritize accessing the numerous professional learning opportunities available for science educators to enhance their knowledge. This increased understanding can elevate sustainability beyond mere recycling to a holistic lens for addressing global challenges.

4.2. Future Impacts

This study suggests that educators' selection of topics to teach and those they omit is primarily dependent on their provided curriculum. Consequently, to effectively cover sustainability topics, a redesign of curricula and curricular resources will need to take place, especially at the elementary and middle school levels, where sustainability is the least taught. The Pennsylvania Department of Education has developed a comprehensive implementation map for the STEELS standards, outlining a framework for curricular integration of the standards (Pennsylvania Department of Education, 2023). This implementation map provides yearly checkpoints for all parties involved—from intermediate units to districts, to administrators, and to classroom educators. According to this framework, during the academic year of this study (2024), classroom educators should be starting to use new curricula and instructional materials, as students will receive standardized tests on STEELS content in upcoming school years. Considering that only 43% of the educators surveyed teach watersheds and wetlands, and 47% teach environmental experiences, it is likely that the STEELS standards are not being taught by most educators. To address this delay, district administrators and curriculum coordinators should seek available support, such as adopting curriculum frameworks, attending implementation and assessment symposia for STEELS, distributing checklists, engaging with the Pennsylvania Science Teachers Association, and leveraging networks such as the PSSE to locate professional learning opportunities.

In line with the SEFT framework (Warren et al., 2014), policymakers, administrators, and educators worldwide should recognize sustainability as a literacy that is just as essential for students to master as reading or math. Shifting to this mindset will be challenging and will require years of consistent effort from multiple stakeholders. Policymakers can require sustainability and EfS to be components of pre-service educators' training. School district administrators can work to find curricula or curricular resources that integrate sustainability concepts and competencies into STEM content areas. To help educators develop confidence and competence to instruct in this area, they can also prioritize professional learning on the multidimensional aspects of EfS. Echoing the thoughts of Munasi and Msezane, professional learning tailored to each grade is essential to address knowledge gaps and maximize the strengths of classroom structures (2024). Therefore, pre-service teacher preparation programs could incorporate EfS concepts into their programs, particularly for elementary educators, where knowledge gaps seem to be the most significant. Additionally, we must also provide impactful professional learning for in-service educators not only in Pennsylvania, but across the U.S. and globally. Previous studies show that long-term professional learning frameworks, which involve educator teams within schools and focus on key sustainability competencies, are more effective than content knowledge alone for driving educational change (Murphy et al., 2020; Redman et al., 2018).

4.3. Limitations

In this study, it is important to acknowledge limitations that may impact the scope of the findings. The survey was accessible only to full-time educators teaching various branches of Pennsylvania's science academic standards, excluding substitute teachers, who are increasingly filling in due to teacher attrition (Department of Education, 2024; Fuller, 2023). This may have skewed the results by excluding potential participants; however, restricting the scope of the survey to full-time educators allowed for clearly defined results.

The main method for survey distribution was by emailing members of the PSSE, which may have limited the survey's scope and reduced its representativeness of the broader STEM educator population. Future research could include substitute teachers and employ broader distribution methods. Additionally, educators with greater sustainability knowledge and experience might have been more inclined to participate in the interviews, possibly influencing the outcomes.

This study did not collect specific details on how educators taught the sustainability topics that they indicated they covered. While these topics are interdisciplinary and related to sustainability, the methods and the extent to which the multidimensional aspects of the topics are presented remain unclear. While the interviewed educators discussed their approaches to teaching sustainability topics, it remains unclear whether these practices are representative of the broader STEM educator population. Future research could explore this area in greater depth to provide a more comprehensive understanding of current practices in STEM classrooms.

5. Conclusions

To prepare students for sustainability-focused careers and to address pressing sustainability issues locally and globally, it is imperative to foster the development of sustainability competencies. This study aimed to discover the extent to which K–12 STEM educators in Pennsylvania use sustainability topics in their classrooms. The results revealed surface integration of sustainability topics, focused on environmental aspects and lacking the integration of competencies such as futures thinking. Additionally, this study explored the factors that influence teachers' inclusion of sustainability into curricula, and we found that key barriers are time and curriculum constraints. This points to the need for paid, professional learning opportunities that build teachers' competencies in sustainability.

High school educators demonstrated a deeper understanding of sustainability compared to elementary and middle school educators. Although the reasons for this difference are currently unclear, this could be an area for future research. Additionally, educators who actively sought to incorporate sustainability were more successful in doing so, with strengths in areas like agriculture and local environmental issues, although improvements are needed in topics like watersheds and wetlands.

While Pennsylvania is advancing the integration of sustainability through the STEELS standards, concerns remain about educators' preparedness, particularly at lower grade levels. Targeted professional development and greater awareness of available resources are needed to equip educators to teach sustainability topics, which will, in turn, help achieve SDG target 4.7.

Author Contributions: Conceptualization, J.A.C., C.M. and E.R.; methodology, J.A.C.; validation, J.A.C., C.M. and E.R.; formal analysis, J.A.C.; investigation, J.A.C.; data curation, J.A.C.; writing—original draft preparation, J.A.C.; writing—review and editing, C.M. and E.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by Institutional Review Board of University of Wisconsin-Stevens Point (2023-79 01/10/2024) for studies involving humans.

Informed Consent Statement: Informed consent was obtained from all subjects involved in this study.

Data Availability Statement: The original contributions presented in this study are included in the article; further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A.

Appendix A.1. Sustainability Content Knowledge and Scoring Rubric

How would you define "sustainability"?

Table A1. Scoring rubric for sustainability definition (Brandt et al., 2019).

Time Perspective		
Score	Meaning	Exemplary answer
0	No time perspective mentioned	-
1	Future perspective	"Something that will last a long time or forever".
2	Intergenerational perspective	"I would define sustainability as responsible use of natural resources today to preserve them for future generations"
3	Inter- and intra-generational perspective	"I believe it is using natural resources in a reasonable manner that they are available for current and future generations".
Dimension Orientation		
Score	Meaning	Exemplary answer
0	No dimensions mentioned	-
1	One dimensional perspective	"Saving the planet from further loss, natural resources used smarter".
2	Multidimensional perspective	"When you consider the equitable balance of "people, planet, profit".

Appendix A.2. Perceived Importance of EfS in the STEM Classroom

Indicate how much you agree with each statement below:

- Teachers can play an important role in solving environmental problems through education (strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, strongly agree).
- It is important to include education for sustainability in my classroom practice (strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, strongly agree).
- Sustainability education is a fad that will pass in time (strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, strongly agree).
- It is important to include education for sustainability in teacher education programs (strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, strongly agree).
- The inclusion of education for sustainability in teachers' professional learning would directly benefit my ability to teach students about sustainability (strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, strongly agree).
- I actively seek to integrate sustainability topics in my teaching (strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, strongly agree).

Appendix A.3. Use of Sustainability as a Context in the STEM Classroom

Please select YES or NO to specify whether you have used the following topics as a context when teaching ${Q104/ChoiceTextEntryValue} during the past two years:

- Agricultural and food systems (e.g., food production, sustainable use of natural resources) (yes/no);
- The effects of social and cultural beliefs on the environment (e.g., environmental and social impacts of personal actions, environmental and social impacts of design solutions, how cultures use and manage resources differently) (yes/no);

- Watersheds and wetlands (e.g., personal influence and dependence on your local watershed; how policies, issues, and technologies impact watersheds and water resources) (yes/no);
- Local environmental issues' impact on larger systems (e.g., how local issues of water pollution can effect larger bodies of water) (yes/no);
- Environmental experiences (e.g., field experiences, community investigations) (yes/no);
- Evaluation of environmental solutions (e.g., determining the effectiveness of renewable energy initiatives and proposing solutions, examining the impacts of storm drains and proposing solutions for runoff) (yes/no);
- Designing solutions to promote environmental stewardship and community well-being (e.g., promote environmental stewardship such as community cleanups, recycling, and land preservation.) (yes/no);
- Inequitable effects of environmental hazards on particular populations (e.g., air pollution negatively effects the health of those in urban areas more than those in rural areas). (yes/no).

Appendix A.4. Justification for the Use (or Lack Thereof) of Sustainability as a Context in the STEM Classroom

You indicated that you have used the following contexts when teaching ${Q104/ChoiceTextEntryValue} during the past two years:

${Q80/ChoiceGroup/SelectedChoicesForAnswer/16}

Please indicate the reason(s) for your response:

- ☐ This context is connected to the standards I teach.
- ☐ It is a part of the curriculum.
- ☐ This context is relevant to my students.
- ☐ I feel knowledgeable to instruct with this context.
- ☐ This context is of interest to me.
- ☐ This context is of interest to my students.
- ☐ Other.

You indicated that you have not used the following contexts when teaching ${Q104/ChoiceTextEntryValue} during the past two years:

${Q80/ChoiceGroup/SelectedChoicesForAnswer/17} Please indicate the reasons for your response:

- ☐ It's not connected to the academic standards.
- ☐ It is not a part of the curriculum.
- ☐ I don't feel this topic is relevant to my students at this time.
- ☐ I don't feel knowledgeable enough to instruct with this context.
- ☐ This context is not of interest to me.
- ☐ This context is not of interest to my students.
- ☐ I don't have the time to instruct using this context.
- ☐ Other.

Notes

[1] Although some argue that EfS, ESD, and sustainability education are interchangeable terms (Grosseck et al., 2019), each carries its own implications. ESD's inclusion of "development" may overlook growth limitations, aligning more with conventional economic perspectives, which can hinder sustainability efforts (Kioupi & Voulvoulis, 2019). Therefore, this article uses the term education for sustainability (EfS).

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