

Exploring Systems Thinking among Science, Technology, Engineering, and Mathematics Educators to Advance Education for Sustainability

Jessica A. Cordaro^{1,2*}, Cliona Murphy³, Jeremy Solin⁴

¹School of Education, University of Wisconsin, Stevens Point, Wisconsin, USA, ²Department of Undergraduate Education and Graduate Education, School of Education, Wilkes University, Wilkes-Barre, Pennsylvania, USA, ³Centre for Advancement of STEM Teaching and Learning, Institute of Education, Dublin City University, Dublin, Ireland, ⁴Division of Extension, University of Wisconsin, Madison, Wisconsin

*Corresponding Author: jessica.cordaro@wilkes.edu

ABSTRACT

While systems thinking is recognized as a main competency of science, technology, engineering, and mathematics (STEM) education and education for sustainability (EfS), the ways educators apply these skills in the classroom and how they shape instruction remains unclear. This study investigates systems thinking competence among STEM educators and its impact on the integration of sustainability topics and content into the curriculum. Using a mixed methods approach, data were collected from STEM educators across the U.S. state of Pennsylvania. The results indicate that high school educators tend to have higher systems thinking competence, place greater importance on EfS, and more frequently incorporate sustainability topics into their lessons compared to elementary educators. In addition, a positive correlation was found between an educator's systems thinking competence and their perceived importance of EfS. These findings suggest the potential value of supporting the development of systems thinking skills among K-12 educators, particularly those teaching lower grades, which may help strengthen their perceptions of the importance of EfS and support related educational outcomes.

KEY WORDS: Education for sustainability; science education; science, technology, engineering, and mathematics education; systems thinking competence; teacher education

INTRODUCTION

Students in K-12 classrooms today face a future vastly different from our present world. They will face new challenges and careers, likely entering diverse sustainability-related fields, many of which do not currently exist (National Academies of Sciences, Engineering, and Medicine, 2020). To prepare students to meet those challenges and be successful in future careers, we must not only teach content knowledge but also develop students' competencies: The knowledge, skills, and attitudes that can be transferred across domains into new situations that have yet to surface (National Research Council, 2012b).

One competency that is a focus of instruction is systems thinking, which is defined as "the ability to recognize the elements and complexity of a system, to understand the interrelationships of the elements, and to appreciate the impacts of the interrelationships at local, national, and global levels" (Demssie et al., 2023, p.264). These general principles can span diverse fields of study, from sciences to business management, allowing systems thinkers to reframe problems, opening up a new set of possible solutions (Cabrera et al., 2008; Senge, 1990).

Because science, technology, engineering, and mathematics (STEM) education emphasizes skills for solving real-world

interdisciplinary problems, systems thinking is a key competency that can be developed through STEM education to prepare future STEM professionals (Martin-Paez et al., 2019). Similarly, education for sustainability (EfS) focuses on the development of competencies to create an educational shift that puts the well-being of the planet and all beings at the forefront, with systems thinking being considered a key competency in this area (Abrom et al., 2021; Cordaro and Murphy, 2025; Nolet, 2009; Nolet, 2015; Redman and Wiek, 2021). While similarities among competencies exist between these educational approaches, there is a dearth of research on the extent to which STEM educators intentionally develop key EfS competencies and teach STEM through sustainability content, which leaves the two approaches feeling disjointed.

LITERATURE REVIEW

In recent years, STEM education has become a widely recognized area of educational practice and research globally. Although existing literature on STEM education reveals different conceptualizations of the purpose and pedagogies that are best practice, many scholars contend that STEM should not be viewed as a subject, but rather a literacy (Aguilera et al., 2021; Falloon et al., 2020). This literacy includes knowledge of STEM disciplines and the skills to ask questions, explain

the surrounding world, and use evidence to draw conclusions and address STEM-related issues (Bybee, 2013). It is widely accepted that the goal of STEM education is not just learning content but also about supporting learners in developing competence, or attributes needed for action (Kloser et al., 2018; McLoughlin et al., 2020). Furthermore, there is general agreement that these competencies align with 21st-century skills like systems thinking, critical thinking, and collaboration skills (Cordaro and Murphy, 2025; Martin-Paez et al., 2019; McLoughlin et al., 2020).

Similar to STEM education, EfS is a growing area of educational practice and research. Emerging from environmental education, this type of learning requires new ways of thinking and problem-solving, keeping the well-being of the planet, people, and other beings at the forefront, transforming the relationships between humans, the natural world, and other beings (Abrom et al., 2021; Nolet, 2009; Nolet, 2015). A central aspect of EfS is its focus on developing competencies rather than merely learning facts (Redman and Wiek, 2021; Sterling et al., 2017). While various competency frameworks exist within EfS, there is broad agreement on the key outcomes, which include the following competencies:

- Critical thinking: questioning norms, values, and opinions, reflecting on views and actions
- Systems thinking: recognize, understand, and analyze systems, to think about how systems are embedded in other systems
- Interpersonal: Collaborate meaningfully with diverse parties
- Normative: Understanding the norms and values that underlie actions and negotiate values, principles and goals of those with conflicting interests
- Strategic: Develop and implement viable strategies toward sustainability; and
- Anticipatory: Visualize multiple futures, create a vision for the future; analyze the consequences of actions (Cordaro and Murphy, 2025; Corres et al., 2020; Redman and Wiek, 2021; UNESCO, 2017; Wiek et al., 2011).

Although STEM education and EfS are often viewed as separate approaches, they ultimately pursue similar outcomes. In 2013, Rodger Bybee, a well-known and influential author in STEM education, stated, “One of the most significant challenges centers on introducing STEM-related issues such as energy efficiency, climate change, and hazard mitigation and developing the competencies to address the issues students will confront as citizens” (p.3). He continued, “Addressing this challenge requires an educational approach that first places life situations and global issues in a central position and uses the four disciplines of STEM to understand and address the problem.” (p.3) These quotes suggest that Bybee envisioned using sustainability problems, encompassing the interplay of environmental, social, and economic aspects of issues, as a context for STEM education. Similar statements showing the purpose of STEM education as addressing complex, transdisciplinary issues can be found across STEM literature,

showing a connection between these two areas (Ling et al., 2019; Pitt, 2009; Zeidler, 2016). Despite these connections, there are gaps in the research, with only a limited number of studies conducted in this field (Lathifah et al., 2024). To address this gap, the present study sought to explore the extent to which sustainability issues are used to engage K-12 students in meaningful STEM learning.

A key similarity of STEM education and EfS is the focus on competency development. The ability to think in systems has been considered one of the most critical competencies for sustainable development globally and is considered one of the main competencies needed by STEM professionals (Demssie et al., 2023; Jang, 2016). When examining the literature from K-12 STEM education and K-12 EfS, systems thinking appears as a key competence of both educational initiatives (Cordaro and Murphy, 2025). Systems thinking components are embedded throughout the K–12 curriculum as a crosscutting concept in the Next Generation Science Standards (NGSS), which 39 U.S. states and the District of Columbia have adopted or used as a framework for science education (Achieve, 2018; National Research Council, 2012a). Regarded as an engineering habit of mind and often thought of in the context of information technology systems or engineering, systems thinking is also necessary for engineering fields, making it a vital competency to integrate throughout STEM education (National Academy of Engineering, 2010).

The Sustainability Education Framework for Teachers (SEFT), the theoretical lens for this research, emphasizes the importance of educators having the necessary competence to effectively teach EfS (Figure 1). By examining topics through and developing proficiency in four competencies (systems

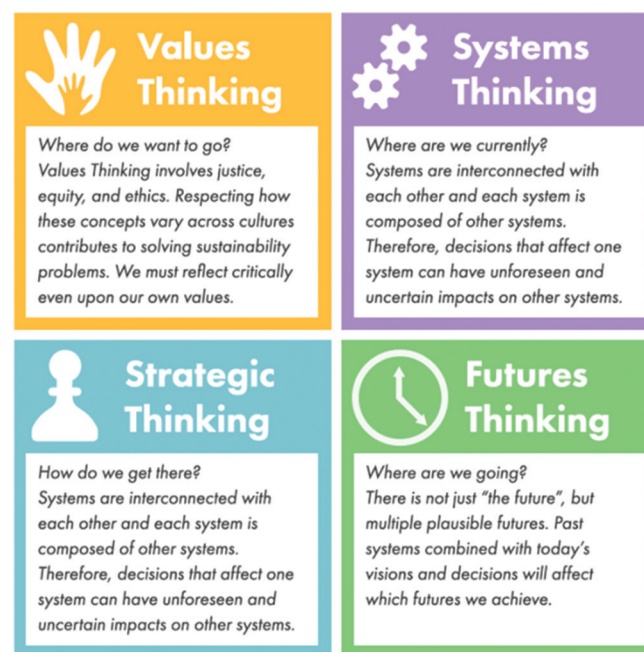


Figure 1: Sustainability education framework for teachers framework (Warren et al., 2014)

thinking, futures thinking, values thinking, and strategic thinking), SEFT aims to enhance educators' understanding of the complexities of sustainability, its solution-driven nature, and its relevance to their roles as both educators and citizens (Warren et al., 2014). Warren et al. contend that mastering these competencies equips educators to teach sustainability effectively and engage critically and strategically with society (2014). The SEFT framework assists educators in linking sustainability topics with content areas, bridging what may be perceived as disparate elements for those lacking sustainability literacy.

Although systems thinking is recognized as a key aspect of STEM education, research on K-12 educators' competence in this area remains limited. Existing studies, summarized below, reveal mixed results, and very few, if any, specifically focus on STEM educators – none of which have been conducted within the United States. One such study measuring the impact of an EfS professional learning program using a systems thinking scale and concept maps found that 39 Turkish educators from various subjects already revealed strong systems thinking skills before participating (Ateskan and Lane, 2018). However, a study of 108 German pre-service biology and geography educators that used a different instrument to test the impact of a professional learning program displayed limited systems thinking competence when given a 23-item test before interventions (Fanta et al., 2020). In this study, older pre-service educators demonstrated greater competence than younger pre-service educators. Similar results were obtained from a study using another instrument with 424 pre-service primary school educators from Norway, Sweden, and Finland, that sought to establish a baseline of systems thinking skills regarding sustainability using a questionnaire and an open-ended question. The results revealed a low level of systems thinking related to ecological sustainability; however, older pre-service educators showed a higher level of systems thinking competence (Palmberg et al., 2017). These findings indicate that educators have various levels of systems thinking competence, with the age of educators potentially influencing their development, indicating a possible correlation between life experiences and systems thinking competence. Given the mixed results of these studies, it would appear that there is a clear need for further research in this area.

SIGNIFICANCE OF THE CURRENT STUDY

STEM education scholars emphasize the importance of using real-world sustainability problems to enhance content knowledge and develop 21st-century competencies (Alkair et al., 2023; Bybee, 2013; Zhou et al., 2022). This study aims to fill the research gap in how STEM educators integrate sustainability contexts into their lessons, offering insights into sustainability contexts in K-12 STEM learning and bridging the research-to-practice divide.

In addition, while systems thinking is a key competency in EfS and STEM education, there appears to be a dearth of research

on STEM educators' systems thinking competence and how it influences their teaching, particularly regarding the use of sustainability topics and their views of EfS. Addressing this gap can improve teacher preparation and professional learning, which, in turn, could enhance both STEM education and EfS.

The aims of this study were twofold. First, it aimed to explore how K-12 STEM educators use sustainability topics as a context for STEM lessons and projects. Second, it sought to determine the level of systems thinking competence among STEM educators and whether this variable correlates with their use of sustainability topics in STEM education and perceived importance of EfS. These aims were explored through the following research question: To what extent do K-12 STEM educators' level of systems thinking competence affect the extent to which they use sustainability topics as a context in STEM lessons and projects?

METHODOLOGY

Research Design

This study aimed to gain both a broad and in-depth perspective of systems thinking competence and sustainability classroom integration among K-12 STEM educators. While quantitative research effectively maintains the objectivity of large datasets to generalize trends, patterns, and similarities, qualitative research allows for subjective interpretation and focuses on smaller samples (Ravid, 2020). A convergent mixed methods approach was therefore chosen for this study, where qualitative and quantitative data were collected at the same time, then analyzed separately before comparing the results to strengthen the validity of findings (Creswell and Creswell, 2018; Thurmond, 2001).

STEM educators from across the U.S. state of Pennsylvania who teach in grades K-12 participated in this study. Due to the ambiguity of defining a STEM educator in Pennsylvania, any full-time educator who taught the science, technology and engineering education, or environment and ecology branches of the Pennsylvania Department of Education Academic Standards was eligible for participation in the study. Voluntary convenience and snowball sampling methods were used to gather a sufficient sample size. The survey link was emailed to Pennsylvania Statewide STEM Ecosystem (PSSE) members, a network of approximately 1,000 STEM educators collaborators, encouraging them to share it with additional eligible educators (Welcome to PSSE, 2026). In addition, survey links were shared on social media groups for STEM educators across Pennsylvania. These approaches permitted participants to self-select and share the survey, though they may have introduced bias and not fully represented the broader population by limiting the distribution to those connected to the PSSE or its members.

Out of 104 educators who responded to the survey, seven did not meet the eligibility criteria, 17 opened the survey but did not answer any questions, and 14 had incomplete submissions,

leaving 68 eligible responses. Due to six of these responses teaching across varied grade ranges (K-12), the analysis of these responses proved challenging and, therefore, were excluded, leaving 62 complete responses that were analyzed. Out of these, 17 educators taught elementary (K-5), 17 taught middle school (6–8), and 28 taught high school (9–12). Years of teaching experience varied: 20 had 1–10 years, 27 had 11–20 years, and 15 had over 20 years, showing diverse experience levels among respondents. A summary of the demographic information regarding the participants is shown in Table 1 below.

Seven virtual interviews were conducted to provide detailed insights into the survey responses. The interviewees included two elementary, two middle school, two high school educators, as well as one who taught both middle and high school STEM courses. Their teaching experience ranged from under 10 years of experience (four educators) to 11–20 years (three educators). They taught a variety of subjects, including elementary science, gifted support, STEM/STEAM, biology, environmental biology, and carpentry.

Data Collection and Analysis

A survey and virtual interviews were the instruments used to gather data from the participants.

Survey

Data were gathered from participants at their convenience through an online survey created using Qualtrics. In addition to demographic information, a combination of Likert-style questions, close-ended responses, and open-ended responses were used to collect data on the constructs of perceived importance of EfS, use of sustainability topics as contexts in the classroom, and systems thinking knowledge and competence (Appendix A). A survey draft was piloted with a small group of educators to ensure clarity and relevance, enhancing the reliability and validity of the instrument. Each construct measured and a description of the questions is briefly described below.

A modified version of the perceived relevance of EfS scale, a 5-point Likert scale (Tomas et al., 2017) was used to gauge EfS importance in STEM classrooms. Modifications tailored questions for K-12 educators and included slight changes in language without altering meaning. An additional question, “I actively seek to integrate sustainability topics in my teaching,” was introduced to explore integration efforts.

Table 1: Cross-tabulation: grades taught and years in education

	Years in Education			Total
	10 years or less	11 to 20 years	21 or more years	
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

Systems thinking competence was measured in two ways on the survey: A scenario-based assessment and an open-ended question requiring participants to define systems thinking. The scenario-based assessment was combined with a revised version of the systems thinking scale by Dolansky et al. (2020) with a vignette-based questionnaire. Participants rated their agreement with responses to a vignette using a 5-point Likert scale. To assess the participants systems thinking definition, a rubric was developed by the researcher with input from systems thinking experts to analyze three main components of systems thinking: relationships of parts to wholes, perspectives, and time delays, scoring responses on a scale from 0 to 7 (Appendix B).

To measure the use of sustainability topics in STEM classrooms, participants were given eight sustainability-related topics and asked to indicate if they used each in their classroom in the past 2 years. The topics align with the environmental literacy and sustainability domain of the science, technology and engineering, and environmental literacy and sustainability (STEELS) standards, adopted statewide in 2024 (Pennsylvania Department of Education, 2023).

Descriptive and inferential statistical analyses were used on the survey data. Descriptive statistics provided a concise summary of participant characteristics and their sustainability integration in the classroom while inferential statistics enabled drawing conclusions and generalization about STEM educators (Creswell and Creswell, 2018; Ravid, 2020).

Interview protocol

Virtual, semi-structured interviews were conducted to gather more detailed data regarding the measured constructs. Mirroring the survey structure, participants were first asked about their work and academic background, STEM education knowledge, and current role. Next, they discussed their understanding of sustainability and its significance in the STEM classroom. Participants then described using eight sustainability topics over the past 2 years, elaborating on lessons. Finally, they defined systems thinking and discussed its relevance in the STEM classroom (Appendix C).

The interviews were recorded, transcribed, and coded using Dedoose, a qualitative coding software. Inductive thematic analysis unveiled several themes which will be discussed in the following sections (Braun and Clarke, 2006). The qualitative data were triangulated with quantitative data from the survey to provide the research findings.

Reliability and Validity

Efforts were undertaken to ensure internal consistency among the Likert-scale items and inter-rater reliability of the scored sustainability and systems thinking responses. Cronbach’s alpha was calculated for both the perceived importance of EfS in the STEM classroom scale and the systems thinking competency scale, with values of 0.752 and 0.567, respectively. The calculated value of 0.752 for the perceived importance of EfS in the STEM classroom scale indicates an acceptable

internal consistency. The calculated value of 0.567 for the systems thinking competency scale indicates relatively low internal consistency. The relatively low reliability of the systems thinking competency scale may be attributed to the limited number of items included in the scale. Six items were included in the systems thinking competency scale to minimize survey fatigue. In addition, systems thinking is a multidimensional construct, with the short scale including measures for patterns of events, feedback, interrelations of factors, sequence of events, and causal sequence. Consequently, some degree of variation among the responses is possible and expected. Interrater reliability for the systems thinking definitions resulted in a value of 0.862, which indicates a high level of agreement. This value suggests that the primary researcher's scores closely align with those of the additional raters. In addition, educators were carefully selected for interviews, ensuring representation across all surveyed grade levels.

FINDINGS

The findings from this study stem from analyzing data collected from the online survey and seven interviews. They are organized into the primary constructs analyzed through the data analysis: systems thinking knowledge and competence, perceived importance of EfS integration of sustainability concepts into STEM education, and relationships between systems thinking competence and sustainability integration.

Systems Thinking Knowledge and Competence

Systems thinking competence and knowledge were measured in two ways: A written definition of systems thinking and a scenario-based assessment, the results of which are summarized in Table 2. Overall, educators across grade levels showed low levels of systems thinking knowledge (mean [M] = 1.95, standard deviation [SD] = 1.093) out of a maximum score of seven, with the highest levels evident among educators of grades 9–12 (M = 2.21, SD = 4.408). The area where the participants scored the highest was in “part to wholes” (M = 1.61, SD = 1.228) with a maximum score of three, followed by “perspectives” (M = 0.31, SD = 0.667), with a maximum score of two. The lowest area was “time delays” (M = 0.03, SD = 0.224), with a maximum score of two. These findings can be interpreted as STEM educators showing a good understanding of the fact that systems thinking involves parts to whole; however, they exhibit minimal to no understanding of its time delays and perspective aspects.

Although systems thinking knowledge was minimal among the educators surveyed, systems thinking competence was high (M = 44.61, SD = 4.150), with high school and middle school educators demonstrating more knowledge than elementary educators (maximum possible score was 55). A one-way analysis of variance (ANOVA) revealed that these differences were approaching significance ($F [2,59] = 2.611$, $p = 0.082$), suggesting a potential connection between the grade level taught and systems thinking competence.

Previous research indicates that life experience could influence the development of systems thinking skills (Fanta et al., 2020; Palmberg et al., 2017). To investigate this relationship, the systems thinking knowledge and systems thinking competency data were analyzed by years of experience in education, the results of which are found in Table 3.

The results indicated that educators in this study with 11–20 years teaching experience had the highest scores, followed by those with 10 or less years of teaching experience, and finally those with 21 or more years teaching experience. However, using a threshold $p = 0.05$, a one-way ANOVA revealed that these findings were not statistically significant ($F[2,59] = 0.393$, $p = 0.667$). Still, differences in systems thinking competence among the groups of educators approached statistical significance ($F[2, 59] = 2.798$, $p = 0.069$), suggesting that age may influence the development of systems thinking competence.

Qualitative data were analyzed to gain a deeper insight into the quantitative findings. Common themes emerged when qualitatively analyzing the responses, the most prevalent being the concept of “connections among parts.” Over half of the surveyed educators ($n = 37$) included this theme in their definitions (Table 4, Quote 1). This example suggests the participants understood that systems thinking is centered around the interconnections of components, as evidenced by the educator discussing the relations between beings. In addition, the STEM educators surveyed tended to perceive systems thinking as a holistic method for observation and analysis (Table 4, Quote 2). The puzzle analogy provided by this educator illustrates their understanding that systems thinking involves interconnected parts, where the collaboration of the various parts is required to navigate complexities successfully. A common theme from the survey was the value of systems thinking for problem-solving, highlighted in 12

Table 2: Means, standard deviations, and one-way ANOVAs by grade band

Measure	Overall		Grades K-5 (n=17)		Grades 6-8 (n=17)		Grades 9-12 (n=28)		F (2, 59)	significance
	M	SD	M	SD	M	SD	M	SD		
Systems thinking knowledge	1.95	1.093	1.59	1.228	1.88	1.166	2.21	4.408	1.831	0.169
Systems thinking competence	44.61	4.150	42.71	3.405	45.24	3.993	45.39	4.408	2.611	0.082
Perceived relevance of EfS	21.10	4.104	19.88	4.675	20.82	4.475	22.00	3.377	1.483	0.235
Sustainability topics used as a context in STEM lessons	4.42	2.719	3.94	2.883	3.94	2.926	5.00	2.465	1.170	0.317

responses, including Quote 3. These responses indicate that educators see systems thinking as a valuable tool for addressing problems and decision-making.

Interviews revealed themes consistent with the survey findings, showing that more experienced educators tended to exhibit higher levels of systems thinking competence than those with less experience. For example, an educator with 5 years' experience in the field indicated they were not sure what systems thinking means, while another with 15 years of experience was able to provide a more complex explanation (Table 4, Quote 4). Their response highlighted the interconnected nature of actions, emphasizing that nothing operates in isolation and every action has consequences, demonstrating a solid grasp of the relationships and causal loops within systems. Four of the interviewed educators included science concepts in their definition (Table 4, Quotes 5a and b), possibly indicating an innate connection of systems thinking to STEM fields. Although all seven interviewed educators demonstrated that those with more teaching experience had a higher level of systems thinking knowledge than those with less experience, this information alone was insufficient to make a conclusive claim. Further research with a larger sample would be required to validate this pattern and explore other contributing factors.

Perceived Importance of EfS Integration of Sustainability Concepts into STEM Education

In the survey, educators were asked a series of questions to determine their perceived importance of EfS in STEM education. The study findings suggest that the higher the grade level taught, the higher the level of perceived importance of EfS. Table 2 shows an increase in scores for the perceived relevance of EfS when examining the results by grade level. While there is a noticeable difference in the perceived importance across different grade levels, statistical analysis reveals that this was insignificant. When examining these scores by years of experience in education, Table 3 shows no trends in the data. Qualitative data from interviews supported these findings, with all educators agreeing on the importance of integrating sustainability into STEM education. They also noted a distinction between environmental educators, who identify problems, and STEM educators, who can devise solutions, suggesting a perceived role for STEM education in addressing sustainability challenges (Table 4, Quote 6). This quote highlights the educators' perception of a need for STEM and environmental education educators to collaborate, aiming to prevent harm to the environment and use STEM skills and competencies to actively address environmental issues.

Table 3: Means, standard deviations, and one-way ANOVAs by years of experience in education

Measure	10 years or less (n=20)		11 to 20 years (n=27)		21 or more years (n=15)		F (2, 59)	significance
	M	SD	M	SD	M	SD		
Systems thinking knowledge (maximum possible score = 7)	2.00	4.437	2.04	1.192	1.73	0.884	0.393	0.677
Systems thinking competence (maximum possible score = 55)	43.00	4.437	45.81	4.188	44.60	3.043	2.798	0.069
Perceived relevance of EfS (maximum possible score=30)	20.55	4.161	21.85	3.581	20.47	4.912	0.806	0.451
Sustainability topics used as a context in STEM lessons (maximum possible score=8)	5.00	2.294	3.52	2.592	5.27	3.127	2.825	0.067

Table 4: Educator sample responses from interviews.

Concept	Example evidence from interview
Systems thinking knowledge: connections	Quote 1: "everything is related to everything else."
Systems thinking knowledge: holistic analysis	Quote 2: "It's like a puzzle. One part affects the other. Which leads you to the system where you need to work together for a smooth transition."
Systems thinking knowledge: problem-solving	Quote 3: "the ability to see the entire system and/or group of systems in an environment which interact with one another to create and/or solve problem, develop opportunities and influence decisions."
More experienced educators systems thinking definition from interview.	Quote 4: "all of the subjects are connected like you can't do one without the other. And like everything, everything just relies on each other. You can't really teach things, you can't really learn things, you can't really do things in isolation. Because there's gonna be an effect or a consequence, or you need to pull something from something else in one way, shape or another."
Science and engineering inclusion in systems thinking definitions.	Quote 5a: "I don't know if this would be considered systems thinking, but the idea of downstream and upstream effects. Like you change one thing and then that can increase something and then decrease something else." Quote 5b: "Systems, thinking, I mean, like, everything I do is systems thinking, you know. When we think about earth as a system, it's like the biosphere, the geosphere, the hydrosphere, like Earth is one big system...Like, if there's something wrong with your water, then it's gonna mess your hydrosphere, it's gonna mess your biosphere. It's gonna mess up the trees and the plants, the people."
STEM can help create solutions to environmental problems.	Quote 6: "Too often environmental educators get hung up on teaching people to be good human beings that don't make problems...if you create emissions you're a bad person, so stop those behaviors. As opposed to STEM, a teacher can take that same thing and instead be looking for solutions. How can I make cars that have fewer emissions? Things like that... and it is important for the STEM teacher to teach sustainability because their job is going to be to find the solutions."

Participants were shown eight sustainability topics aligned with Pennsylvania's STEELS standards to identify the sustainability themes in their STEM curriculum. Survey findings revealed that the topics most taught across grade levels were agriculture and food systems, and local issues' impact on larger systems, each mentioned by 38 educators. Watersheds and wetlands were the topics least taught, with only 27 educators teaching about them. Few also incorporated environmental experiences or outdoor learning. As shown in Table 2, grades 9–12 educators generally teach more sustainability topics than those in lower grades. The results were not statistically significant; however, they were approaching significance. These findings indicate that the educators surveyed teach about half of the presented topics, with a limited focus on watersheds, wetlands, and environmental experiences, indicating a need for better curricular integration in these areas. The full results are found in Figure 2. Since STEM educators have indicated that they are not teaching these sustainability-related topics, students are likely missing out on important knowledge, creating a significant knowledge gap.

Relationships between Systems Thinking Competence and Sustainability Integration

The primary aim of this research was to determine if a relationship exists between STEM educators' systems thinking knowledge and competence and their integration of sustainability topics into their teaching. Since the data met the assumptions of parametric tests, a Pearson's correlation coefficient was used to examine this relationship. Although the results revealed no correlation between educators use of sustainability topics in STEM content and systems thinking competency $r(60) = 0.026$, $p = 0.840$, or systems thinking knowledge $r(60) = 0.062$, $p = 0.632$, a statistically significant correlation was present among the variables of an educator's systems thinking competency and their perceived importance of EfS $r(60) = 0.299$, $p = 0.018$. These findings indicate that STEM educators with a more developed sense of systems thinking find EfS to be more relevant. Qualitative data from the interviews supported quantitative findings, revealing that educators teaching more sustainability concepts tend to

offer more comprehensive explanations of systems thinking (Table 4, Quotes 4 and 5b), suggesting a correlation between these variables.

DISCUSSION

The data analyzed in this study suggests a trend among educators of different grade levels where educators teaching higher grade levels show increased proficiency in systems thinking and a greater perceived relevance of EfS in STEM classrooms. STEM educators in Pennsylvania generally possess a high level of systems thinking competence, results that align with Ateskan and Lane's Turkish study that used a similar instrument (2018). While not statistically significant, there is a notable trend of increasing systems thinking competence among higher grade-level educators. Curricula for higher grade levels typically focus on content-specific skills rather than more general science concepts taught in elementary grades. As a result, there may be a connection between the education and experience of educators who teach content-specific courses and the development of educator systems thinking competence. Understanding this relationship could inform professional learning initiatives and curriculum design to better integrate systems thinking into STEM education.

These findings also indicate that professional learning and pre-service EfS learning should be grade-level specific. Elementary STEM educators demonstrate low levels of sustainability integration and perceive EfS as less relevant, possibly due to the lack of science-specific content in teacher preparation programs compared to educators of older grades. Therefore, elementary educators may require foundational training in sustainability before learning effective teaching methods. A benefit of elementary educators is that they often teach multiple content areas, offering opportunities for more interdisciplinary instruction. Because of this, their professional learning should emphasize cross-content connections and integrate systems thinking to support interdisciplinary lessons. This approach aligns with Quigley et al. (2017), who advocate for explicit connections across disciplines at the elementary level.

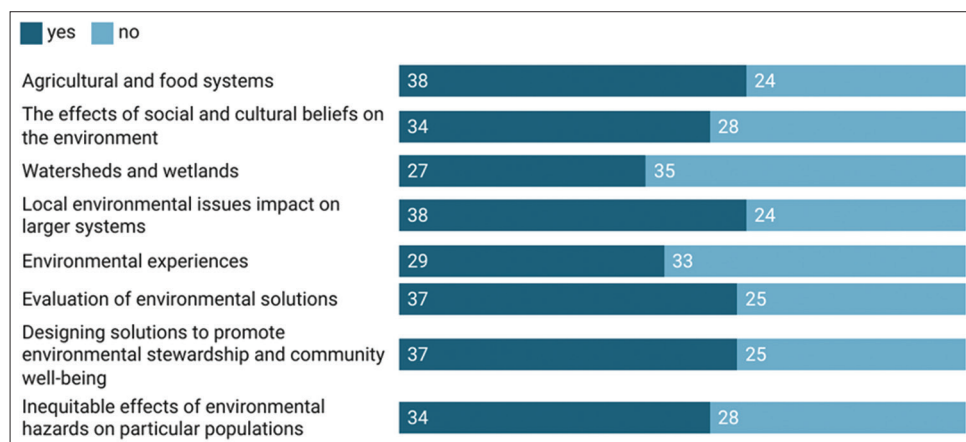


Figure 2: Sustainability topics taught by science, technology, engineering, and mathematics educators

The findings revealed that educators with 11–20 years of experience demonstrate the highest systems thinking competency, approaching statistical significance compared to those with 10 or fewer years' experience. This aligns with prior studies, suggesting age may influence the development of systems thinking development (Fanta et al., 2020; Palmberg et al., 2017). This trend suggests that systems thinking may be more influenced by experience than by formal instruction, highlighting the importance of retaining educators, as those who are older and more experienced tend to have higher levels of systems thinking competence. Investing in mentorship programs and continuing professional learning could help transfer this expertise to early-career educators, strengthening systems thinking across the field.

A positive correlation existed between educators' systems thinking competency and their perceived importance of EfS in STEM education, indicating an interconnectedness between these domains. Although correlation does not imply causation, this finding suggests that increasing systems thinking competence can increase one's perceived importance of EfS, highlighting systems thinking as a pivotal competency in both areas and a means to bridge these educational initiatives. By embracing this concept, we can enhance the clarity of STEM education and elevate EfS globally, strengthening both practices. This idea aligns with the principles of SEFT, which focuses on developing four key competencies of educators to effectively teach sustainability and engage with society critically to make informed decisions (Warren et al., 2014). A higher level of systems thinking competence among educators may not only enhance their ability to teach EfS effectively but also deepen their personal commitment to sustainability. This, in turn, could influence classroom instruction. Future research therefore should explore the causal relationship between systems thinking competence, the perceived importance of EfS, and real-world sustainability actions to enhance teacher professional learning and curriculum reform. Furthermore, since the goal of EfS is to increase sustainability competencies such as systems thinking among students, future studies can measure students' level of systems thinking competence after interventions using formal and informal methods. Examples of assessments are as scenario-based assessments and self-report questionnaires, pictorial tests, systems modeling, and concept mapping (Brandstädter et al., 2012, Davis et al., 2023; Nissel Miller et al., 2023; 2022; Roczen et al., 2021).

Scholars have argued that using a systems thinking approach to frame knowledge can create an opportunity for transferring learning across content areas (Cabrera and Cabrera, 2019). By developing proficiency in systems thinking, educators can link various academic disciplines and address the complex, multi-dimensional aspects of sustainability. Additional training in systems thinking and sustainability can improve educators' understanding of EfS, enhance their sustainability literacy, and boost their confidence in teaching these topics. Since many schools across the United States have adopted NGSS standards or similar multidimensional approaches to science education, providing professional learning for in-service and

pre-service educators on utilizing cross-cutting concepts, specifically systems thinking, can help integrate this approach into existing professional learning.

LIMITATIONS

This study has limitations; firstly, due to the survey distribution methods and scope, it involved a relatively small sample size of 62 survey participants and seven interviewees. While a larger sample size may have influenced the results, maintaining a narrow scope allowed for more clearly defined results. However, it should be noted that the small sample size may have impacted external validity and that the results may not be representative or transferable to the entire population of Pennsylvania STEM educators. Future studies can be conducted on a larger sample of STEM educators using more robust sampling methods. In addition, previous studies have used a variety of instruments to measure systems thinking competence. This study utilized a scenario-based Likert scale assessment; however, alternative instruments may have provided different results. The assessment chosen for this study was considered the most suitable option due to its reliability and ease of use. A variety of other methods for assessing systems thinking competence could be utilized in future studies. These include formal methods, such as scenario-based assessments and Likert-style self-report questionnaires, as well as informal methods, such as pictorial tests, systems modeling, and concept mapping (Brandstädter et al., 2012, Davis et al., 2023; Lavi and Dori, 2019; Nissel Miller et al., 2023; Ratinen and Linnanen, 2022; Roczen et al., 2021). Using these methods, either individually or in combination, may have produced different results.

This study examined eight sustainability topics aligned with Pennsylvania's new science standards (STEELS); however, educators might have incorporated additional sustainability topics beyond these into their lessons. The choice to focus on these specific topics was made because of their significant relevance to Pennsylvania's educational framework. Exploring what sustainability-related topics other than the eight presented are being taught through STEM education could provide a more robust picture and is an area for future research.

CONCLUSION

Cabrera and Colosi (2012) emphasize the need for systems thinking: "Globalization creates more and more links, interconnecting people and places that used to seem separate and unrelated. Problems are no longer contained in their own geographical areas but are linked to and impact other problems across the globe" (p. 122). The problems referred to in this quote imply sustainability related issues, such as poverty, environmental degradation, and climate change, highlighting a need for EfS mainstreamed into educational systems.

This study sought to determine to what extent an educator's systems thinking competence impacted their perceived relevance of EfS and use of sustainability topics in STEM education. The findings indicated that although K-12 STEM

educators had a low level of systems thinking knowledge, they demonstrated high levels of systems thinking competence. The study also found a correlation between an educator's systems thinking competence and their perceived importance of EfS, with educators teaching higher grade levels showing greater competence. These results suggest a need to enhance systems thinking skills among both pre-service and in-service educators to emphasize the importance of EfS in K-12 STEM education. Strengthening these competencies could improve the integration of sustainability topics and help students develop the skills needed to tackle real-world challenges.

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APPENDIX A

Survey Instrument

Informed consent

You are being asked to take an anonymous survey that is part of a research study designed to examine the relationships between STEM educators' understanding of sustainability, how it's used as a context in STEM education, and educator's systems thinking competence. This should take no more than 10 minutes of your time. Your participation is completely voluntary.

The researcher anticipates no risk to you as a result of your participation in this study other than the inconvenience of the time to complete the survey. You could, however, experience some discomfort if you feel you don't know the answer to certain questions. While there is no immediate benefit to you as a result of your participation in the study, the study should gather valuable information that related to systems thinking in K-12 STEM education, which can advance that area of education.

The information you provide on the survey will remain anonymous. We will not release any information that could identify you. All survey data will be kept on a laptop computer drive and cloud-based services that are password protected and will not be available to anyone who is not directly involved with this survey.

Your participation in the survey is completely voluntary and you may end your participation at any time without penalty. Only anonymous information provided will be retained. Any identifiable information will be removed from the study and permanently deleted.

At the end of the survey, you will have the opportunity to provide your contact information to participate in an online interview that will serve as a follow up to the survey. The purpose of the interview is to allow the researcher to obtain more details regarding the survey responses. This portion of the research is will take approximately 30 minutes of your time. The interview is voluntary, and you may choose to not participate or withdraw from participation in the interview at any time without penalty. Your contact information will be used strictly for scheduling an online interview and will be handled using the same security procedures as the other information you provide.

If you have any questions about the survey, please contact:

Jessica Cordaro, University of Wisconsin-Stevens Point
Jcord241@uwsp.edu
570-540-5820

If you have any complaints about your treatment as a participant in this study or believe you have been harmed in some way by your participation, please call or write:

David Barry, PhD

IRB Chair Associate Professor, Sociology

2100 Main St.

Old Main 208

University of Wisconsin, Stevens Point and Extension

Stevens Point, WI 54481

715-346-3799

irb@uwsp.edu

I have read and understand the above consent form. I certify that I am 18 years old or older. by clicking the "Next" button to enter the survey, I indicate my willingness to voluntarily take part in this study.

Eligibility Question

In order to take this survey, you must meet the following requirements:

Be a current, certified educator in Pennsylvania. Teach full-time in a public, private, virtual, and/or charter school. Teach in a grade from kindergarten to 12th grade. Teach any of the following branches of the current PDE academic standards:

- Science Education
- Technology and Engineering Education
- Environment and Ecology (Agriculture)

Do you meet these requirements?

- Yes
- No
- *Skip To: End of Survey If In order to take this survey, you must meet the following requirements: Be a current, certified... = No*

Educator Experience Questions

1. What grade level(s) do you currently teach?

Select all that apply.

- ☐ Kindergarten
- ☐ 1st grade
- ☐ 2nd grade
- ☐ 3rd grade
- ☐ 4th grade
- ☐ 5th grade
- ☐ 6th grade
- ☐ 7th grade
- ☐ 8th grade
- ☐ 9th grade
- ☐ 10th grade

- ☐ 11th grade
- ☐ 12th grade

Which of the following PDE academic standards do you teach?

- Science Education
- Technology and Engineering Education
- Environment and Ecology (Agriculture)

Please specify the name of the course you teach that covers any of the standard sets above.

If you teach more than one course that uses those standards, please write the name of only one course below.

How many years total have you been teaching \${Q104/ChoiceTextEntryValue}?

- less than 1 year
- 1 to 5 years
- 6 to 10 years
- 11 to 15 years
- 16 to 20 years
- 21 to 25 years
- 26 years or more

How many years total have you been a full-time K-12 educator of any subject?

- less than 1 year
- 1 to 5 years
- 6 to 10 years
- 11 to 15 years
- 16 to 20 years
- 21 to 25 years
- 26 years or more

Since you have been over 18 years old, have you had any careers other than a full-time K-12 educator?

- Yes
- No

Display This Question:

If Since you have been over 18 years old, have you had any careers other than a full-time K-12 educa... = Yes

Q121 Briefly specify the career(s) you also had and how long you held that position.

Systems Thinking Competence Questions

Scenario: You reside in an urban area in Pennsylvania. In this city, overcrowded neighborhoods are lacking basic services like healthcare facilities, quality schools, parks, and public transportation. Streets are congested and the lack of pedestrian walkways make navigation difficult. As the city grows, urban sprawl invades natural habitats, threatening biodiversity and further degrading the environment. This expansion also leads to an increase in carbon emissions.

You are on a committee with the vision of revitalization of this urban setting. Answer the following question sets based on how you would respond when trying to improve this area.

1. I actively seek input from city departments and citizens. (Strongly agree, Somewhat agree, Neither agree nor disagree, Somewhat disagree, Strongly disagree)
2. I think specific events are more important than patterns. (Strongly agree, Somewhat agree, Neither agree nor disagree, Somewhat disagree, Strongly disagree)
3. I consider how different groups of citizens may be impacted and react to the proposed changes. (Strongly agree, Somewhat agree, Neither agree nor disagree, Somewhat disagree, Strongly disagree)
4. I consider how actions that took place in the past may have different effects over time. (Strongly agree, Somewhat agree, Neither agree nor disagree, Somewhat disagree, Strongly disagree)
5. I think that significant, lasting change can happen quickly. (Strongly agree, Somewhat agree, Neither agree nor disagree, Somewhat disagree, Strongly disagree)
6. I think specific events are more important than patterns. (Strongly agree, Somewhat agree, Neither agree nor disagree, Somewhat disagree, Strongly disagree)
7. I think the well-being of the people is more important than the well-being of the natural habitat. (Strongly agree, Somewhat agree, Neither agree nor disagree, Somewhat disagree, Strongly disagree)

Systems Thinking Definition: How would you define “systems thinking”?

Sustainability definition: How would you define “sustainability”?

Perceived relevance of EfS: Indicate how much you agree with each statement below.

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

Training on EfS

Have you had any training on education for sustainability?

If, yes, please select the source of your training.

If you are unsure if a training was on education for sustainability, select yes and identify the source.

- Yes, formal training from a university/college course
- Yes, training from an informal workshop/course outside (DCNR, environmental education organizations, etc.)
- No

Sustainability as a context in the STEM classroom (part 1)

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

1. Agricultural and food systems (e.g., food production, sustainable use of natural resources) (yes/no)
2. 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)
3. 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)
4. Local environmental issues impact on larger systems (e.g., how local issues water pollution can effect larger bodies of water) (yes/no)
5. Environmental experiences (e.g., field experiences, community investigations) (yes/no)
6. 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)
7. Designing solutions to promote environmental stewardship and community well-being (e.g., promote environmental stewardship such as community clean ups, recycling, and land preservation.) (yes/no)
8. Inequitable effects of environmental hazards on particular populations (e.g., air pollution negatively effects the health of those in urban areas greater than those in rural areas). (yes/no)

Sustainability as a context in the STEM classroom (part 2):

Display This Question:

If Please select YES or NO to specify whether you use the following topics as a context when teachin... = Yes

You indicated 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 _____

Display This Question:

If Please select YES or NO to specify whether you use the following topics as a context when teachin... = No

You indicated you have not used the following as a 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 _____

Optional interview participation

If you would be willing to participate in a short interview regarding this survey, please follow this link: https://uwsp.az1.qualtrics.com/jfe/form/SV_3f69vqCR5Jb972S

If you are not interested, hit the arrow in the bottom right of the screen.

Thank you for your time and participation in this survey.

To obtain a copy of the results of this study, please contact Jessica Cordaro at jcord241@uwsp.edu.

Optional Interview participation fields

Informed Consent: You are being asked to participate in an online interview that is part of a research study designed to examine the relationships between STEM educators' understanding of sustainability, how it's used as a context in STEM education, and educator's systems thinking competence. The interview should take no more than 30 minutes of your time. Your participation is completely voluntary.

The researcher anticipates no risk to you as a result your participation in this study other than the inconvenience of the time to complete the survey. You could, however, experience some discomfort if you feel you don't know the answer to certain questions. While there is no immediate benefit to you as a result of your participation in the study, the study should

gather valuable information that related to systems thinking in K-12 STEM education, which can advance that area of education.

To contact you for the interview, you will provide your full name and email address. This information will be kept confidential and will only be used for interview scheduling purposes. Throughout the research process and in future publications, your identity will be coded as “educator1”, “educator2”, etc. to ensure privacy. Transcripts and recordings of the interview will be stored on a laptop computer drive that is password protected and will not be available to anyone who is not directly involved with the interview. We will not release any information that could identify you.

Your participation in the interview is completely voluntary and you may end your participation at any time without penalty or refuse to answer any questions without penalty. Only anonymous information provided will be retained. Any identifiable information will be removed from the study and permanently deleted.

If you have any questions about the survey, please contact:

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715-346-3799

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- I have read and understand the above consent form. I certify that I am 18 years old or older. by clicking the “Next” button, I indicate my willingness to voluntarily take part in this study.

If you would be willing to participate in a short interview regarding this survey, please complete the form below.

The researcher will be in contact with you shortly to schedule the online interview.

If you are not interested in participating in the interview, you may close out of this screen.

First Name _____

Last Name _____

Email Address _____

End of Survey

Thank you for your time and participation in this survey.

To obtain a copy of the results of this study, please contact Jessica Cordaro at jcord241@uwsp.edu.

APPENDIX B

Scoring rubric for systems thinking definition

Relationships of parts to wholes		
Score	Meaning	Exemplary Answer
0	No parts, wholes, or relationships mentioned	-
1	Concept of parts/wholes present	"Systems thinking is looking at the whole picture."
2	Interactions among the concert of parts and wholes present	"Systems thinking is how parts of something interact with other parts."
3	Interactions and interdependencies among the concept of parts and wholes present	"Systems thinking is about how the parts of something interact with other parts, depend on each other to make something happen."

Perspectives		
Score	Meaning	Exemplary Answer
0	No mention of perspective	-
1	One-dimensional perspective present	"From my point of view, the [cause] is leading to [effect]."
2	Multi-dimensional perspective present	"Problems can look different depending on where you are in the system"

Time-delays/Changes over time		
Score	Meaning	Exemplary Answer
0	No construct of time present	-
1	One-dimensional aspect of time present (either speaking of the present or the future)	"Systems thinking shows how elements change over time."
2	Long-term and short-term relationships/multi-dimensional aspect of time present	"Systems thinking can show patterns of cause and effect in the short term and also over a longer period of time."

APPENDIX C

- STEM education questions:
 - Tell me more about your educational experience and how you got into STEM education.
 - What do you like and dislike about the current state of STEM education?
- Perceived relevance of EfS:
 - Do you think it's relevant for STEM educators to

teach about sustainability concepts? Tell me more about why you chose that response.

- Tell me about how you actively integrate sustainability topics into your teaching.
- Formal education for sustainability training: Have you had any training on education for sustainability?
 - If yes, tell me more about the training(s) you had on education for sustainability.
 - Where did you complete them?
 - How long ago did you complete the trainings?
 - What were your main takeaways?
 - Have you implemented any of the strategies learned?
 - Why or why not?
 - If no, why have you never engaged in any trainings on education for sustainability?
 - Sustainability as a context in the STEM classroom:
 - Tell me more about if/when you have used those topics as a context for STEM education. What grade level? Why did you choose these topics? What types of pedagogical practices were the students engaged in? How did they respond to the lesson?
 - Agricultural and food systems
 - The 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
 - Designing solutions to promote environmental stewardship and community well-being.
 - Inequitable effects of environmental hazards on particular populations.
 - If they have never taught through these contexts: Tell me more about why you have not used these contexts. Would you feel prepared to teach these about these contexts? What do you think would be needed for you to teach about these contexts?
 - Additional comments: Is there anything else you would like to add?