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Introducing Preservice Elementary Teachers to Permaculture Education

Sonnur Ozturk[1]
Michelle E. Forsythe[2]

Abstract

Current models of best practice in science education advocate for students to learn science by engaging in applied contexts that integrate the various science disciplines. Permaculture offers one such integrated context for elementary science. Although permaculture is relatively new in PK-12 education, the broader practice of school gardening has an established history of supporting student engagement in and conceptual understanding of science. However, many elementary teachers report feeling unprepared to implement garden-based lessons. This article examines preservice teacher (PST) ideas about permaculture and views toward teaching permaculture that emerged within an elementary science methods course. The course's pilot instructional intervention on permaculture included four components: background permaculture readings and videos, guided discussion, food forest design activity, and lesson plan analysis activity. We designed these components to engage preservice teachers both as current learners and future teachers of permaculture. Data was collected from pre/post-tests, the lesson analysis activity, and the PST daily end-of-class reflections. After the permaculture intervention, PSTs self-reported higher levels of knowledge of permaculture topics and ways to use permaculture in their classrooms. They also effectively connected permaculture-based lesson plans to a variety of elementary learning standards. The PSTs positively viewed permaculture-based lessons as providing active, real-life learning experiences that support environmental consciousness, but viewed the cost and time required as barriers to implementing permaculture in their classrooms. Collectively, they positioned the developmental appropriateness and spatial resources required of the lessons as both advantages and disadvantages. Implications for teacher preparation and development are discussed.

Introduction

Current models of best practice in science education advocate for K-12 students to learn the core ideas, practices, and cross-cutting concepts of science through engagement in applied contexts that integrate the various disciplines of science (NGSS Lead States, 2013). Permaculture offers one such integrated context for elementary science. Permaculture is a holistic approach to intentionally designing a forest-like ecosystem of food-producing plants (Bane & Holmgren, 2012). The goal is to create a permanent agricultural system that is automatically regenerative, unlike traditional agricultural systems that must be replanted each year (Holmgren, 2002). Designing a sustainable permaculture food forest or garden requires integrated biology and geoscience skills and knowledge of soil structure, plant and animal needs, microorganisms, biodiversity, patterns and interactions in nature, and climate. Although permaculture is still relatively new in PK-12 education, the broader practice of gardening has an established history of supporting student engagement in and conceptual understanding of science (Blair, 2009; Williams et al., 2018). However, many elementary teachers report feeling unprepared to implement garden-based activities in their classrooms (Graham & Zidenberg-Cherr, 2005). This article examines preservice teacher ideas about permaculture and views toward teaching permaculture that emerged within the context of a small-

[1] Sonnur Ozturk is a doctoral student in the Department of Curriculum and Instruction at The University of Texas at Austin, 1912 Speedway, Stop D5000 Austin, Texas 78712, sozturk@utexas.edu. ORCID# https://orcid.org/0000-0001-8094-9870
[2] Michelle Forsythe is an Associate Professor in the Department of Curriculum and Instruction at Texas State University Education 3045 601 University Dr. San Marcos, Texas 78666, mef104@txstate.edu. ORCID# https://orcid.org/0000-0003-3955-0723

scale pilot instructional intervention on permaculture in an elementary science methods course. Implications for teacher preparation and development are discussed.

Literature Review

Permaculture

Permaculture is a comprehensive approach to gardening that focuses on creating a self-maintaining local ecosystem that supports food-producing plants (Bane & Holmgren, 2012). Mollison and Holmgren (1978) coined the term permaculture by combining the words *permanent* and *agriculture*. Although permaculture is most closely associated with food production, these ethical and design principles also extend into social issues such as community building, economics, and natural resource consumption (Evans, 2015; Luna et al., 2018). Holmgren's (2002) twelve central ethical and design principles of permaculture include: observe and interact, catch and store energy, obtain a yield, apply self-regulation and accept feedback, use and value renewable resources and services, produce no waste, design from patterns to details, integrate rather than segregate, use small and slow solutions, use and value diversity, use edges and value the marginal, and creatively use and respond to change.

One of the most fundamental design elements of a permaculture garden is the food forest. A permaculture food forest uses the complex relationships between food-producing plants, animals, microorganisms, and the landscape to set up a self-sustaining and mutually enhancing ecosystem. The variety of annual and perennial plants in a food forest supports the production of fruits, vegetables, herbs, and edible flowers as well as supply pollinator habitats and natural sources of medicines (Frey & Czolba, 2017). Although the design and construction of a food forest requires substantial initial effort, the self-regulating system increases productivity over time while requiring less maintenance than traditional agricultural approaches (Mollison & Holmgren, 1978). This natural system helps to create a continuous cycle in which the output or waste of one part of the food forest can be an input or food for another part.
Food forest designs are based on the observation and replication of natural patterns in the environment (Taylor Aiken, 2017). According to Holmgren (2002), the most effective permaculture food forests work with nature, not against it. Designing a sustainable food forest requires an integrated understanding of complex biology and geoscience topics, including landscape terrain and elevation, soil structure, sunlight, water cycling, weather, plants, animals, microorganisms, energy transformations, and technology (Bane & Holmgren, 2012). To aid food forest design, Hart (1996) developed a seven-layered model of the food-producing plants in a food forest ecosystem: 1) a canopy layer of tall fruit and nut trees (e.g., black cherry and walnut), 2) a low-tree layer of dwarf fruit and nut trees (e.g., persimmon), 3) a shrub layer of fruit bushes (e.g., currants), 4) an herbaceous layer of herbs and perennial vegetables (e.g., catnip) 5) a ground-cover layer of low edible plants (e.g., strawberries), 6) a rhizosphere layer of root crops (e.g., sweet potatoes), and 7) a vertical layer of vines and climbers (e.g., grapes).

Permaculture in Schools

Schools in the United States have begun to take the principles of permaculture and apply them to their school gardens as part of expanded environmental education initiatives. For example, one PK-12 school created a permaculture-based school garden that was designed to minimize the garden's environmental impact (Praetorius, 2006). While working in the garden, students gathered systematic observations about the weather, sunlight, soil, and plants. These garden-based investigations promoted students' environmental awareness. Another elementary school applied permaculture design to create an on-site biodiverse food forest ecosystem (Morgan, 2017). This food forest served as the focal context for student explorations of plant and animal structures, lifecycles, soil, and ecological interactions. It also provided students and staff with fresh fruits, vegetables, and herbs.

Permaculture-based science education has also gained traction internationally, particularly in Australia and New Zealand. For example, in Australia, a multi-site study of primary students involved in planning, installing, harvesting, and cooking activities related to a permaculture garden found that the project provided a meaningful way to promote the teaching of values and to introduce students to whole systems thinking (Lewis et al., 2008). Similarly, a study of sustainability education in junior secondary science classrooms in New Zealand showed a positive impact on students' attitudes toward sustainable thinking which helped to enhance students' learning of science. (Lebo et al., 2013). Most teachers in this study reported that permaculture helped them to contextualize science teaching with real-world examples. The teachers also responded that by implementing the sustainability curriculum they personally had developed a better understanding of sustainability and more positive attitudes toward permaculture education in schools. In another study of secondary science students and teachers, Lebo and Eames (2015) showed an instructional intervention emphasizing sustainable food production had positive impacts on both the teacher and students. Students not only reported that learning science was more fun in the garden, but they also developed a stronger understanding of science concepts such as seed germination, soil, and biological diversity.

PK-12 Science Learning in School Gardens

Although permaculture-based gardens have only begun to permeate PK-12 science education, the broader practice of gardening in schools has an established history of supporting student learning (Blair, 2009). Teachers use school gardens as an anchoring experience to unify science concepts for elementary students within an applied and practical context (Graham et al., 2004; Graham & Zidenberg-Cherr, 2005; Nyberg, 2014). In a review of school gardening in the United States elementary schools, Blair (2009) examined the instructional design of garden-based learning activities and the positive impacts of these activities on student learning outcomes. Blair found that elementary teachers used school gardens as the site for interdisciplinary learning experiences in which students observed natural processes, conducted field-based experiments, and learned about a range of core disciplinary topics from soil and seeds to life cycles and recycling. Kelley and Williams (2013) also found that teachers who participated in gardening-based professional development alongside students in local gardens were impacted by how the learning experience promoted interdisciplinary and collaborative learning and supported discussions and action regarding social justice in the community.

Research conducted on the effectiveness of school gardens found numerous academic benefits for students. One systematic review of 48 research studies on school gardens concluded "overwhelmingly that garden-based learning had a positive impact on students' grades, knowledge, attitudes, and behavior" (Williams & Dixon, 2013). For example, in a large quasi-experimental study of over 600 elementary students, students who participated in school-based gardening activities in addition to their traditional science classroom activities had higher scores on science achievement tests than students in the control group who only participated in the traditional activities (Klemmer et al., 2005). Garden-based learning activities were also found to support middle school students' engagement in science and student learning of scientific concepts (Williams et al., 2018). Knobloch, Ball, and Allen (2007) found that learning experiences in school gardens are connected to hands-on activities, real-life experiences, and concrete examples that provide meaningful learning experiences to students. In an international comparative study of English, Indian, and Kenyan schools, Bowker and Tearle (2007) explored children's perceptions and understanding of school gardens and found that gardening experiences positively influenced students' affective learning, attitude towards school, and self-confidence. Indian and Kenyan students also frequently related their experiences with school gardening to wider environmental issues, such as weather and climate change, agricultural practices, and food security.

Despite this evidence about how gardens can enhance students' learning, teachers perceive numerous barriers to using school gardens to teach science. In a study of elementary teachers' attitudes toward school gardens, Graham and Zidenberg-Cherr (2005) found that few teachers view the amount of time required to be the greatest barrier to using gardens in their classrooms, followed closely by teachers' lack of interest in gardening. Teachers also reported a lack of experience and confidence with gardening and a lack of garden-based curricular materials connected to academic standards (Graves et al., 2016). Other research has found similar barriers to school gardens, including a lack of teachers' knowledge and training (Blair, 2009), a lack of funding for gardening supplies (Smith et al., 2019), a lack of space for gardening and storing gardening tools (Burt et al., 2018), and a lack of support maintaining the garden (Burt et al., 2019). Collectively, these studies highlight logistical, curricular, and personal impediments to school-based gardening.

Preservice Science Teacher Learning in School Gardens

Garden-based learning activities have also been used to support PSTs in developing positive dispositions and self-efficacy toward teaching science. Trauth-Nare (2015) found that PSTs who participated in practicum-based gardening activities with students positively shifted their perceptions of supporting student success in environmental science. Similarly, elementary PSTs who assisted with school-based gardens described how the gardening experience encouraged an asset-based perspective that highlighted student strengths and positioned students as curious, knowledgeable, engaged, and interested (Wilson et al., 2015). These experiences can also bring salience to broader educational issues, such as the need for gender-inclusive science teaching (Wallace, 2013).

Though these previous studies of PSTs involved on-site gardening, they did not focus on permaculture. As highlighted above, most research on permaculture education has focused on PK-12 schools, students, and in-service teachers. The exploratory study presented in this article aimed to address this gap in the literature by examining PST perspectives of permaculture and views toward teaching permaculture.

Conceptual Framework: Integrated Science Learning

Although much of the science curriculum is often taught discretely (Michaels et al., 2008), students' learning is more effective in science when the curriculum is conceptually integrated (Nogay, 1994). Current reforms in science education, such as the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013), the 4-Dimensional Ecology Education (4DEE) Framework (Berkowitz et al., 2018), and the K–12 Environmental Education: Guidelines for Excellence (NAAEE, 2019), recommend that the discrete elements presented in these documents be blended in science teaching and learning. Curriculum integration can take many forms: blending dimensions of science (science practices, core ideas, and cross-cutting concepts) (NRC, 2012), blending domains or disciplines of science (biology, geology, chemistry), or blending traditional subject areas in interdisciplinary learning (science, math, art, English language arts). The commonality across all these integrated approaches is that students are using and making connections between curriculum elements. Teachers report numerous cognitive and motivational benefits for students when using integrated and interdisciplinary curriculum: greater depth of understanding; improved retention and transference of knowledge; ease in communicating understandings; and increased engagement, excitement, and interest (Brand & Triplett, 2012).

Permaculture presents a disciplinary context in which teachers can teach the many dimensions, domains, and applications of science from an integrated learning perspective. Learning activities that emphasize sustainability, such as permaculture gardens, support elementary students in whole systems thinking (Lewis et al., 2008). Elementary teachers have used school gardens to integrate different topics in science such as weather and plants (Praetorius, 2006), to construct interdisciplinary science, math, and literacy learning experiences (Blair, 2009), and to connect student's science learning to meaningful local contexts (Eick, 2012). The ethical principles of permaculture (Holmgren, 2002) also highlight the social dimensions of science and can be used to connect to broader educational concerns, such as equity and social justice (Kelley & Williams, 2013) and critical STEM pedagogy (Luna et al., 2018).

Gardening in general and permaculture-based gardening specifically provides an integrated context in which science teachers could anchor student investigations of multiple standards-based disciplinary foci.

Appendix A details select standards from the NGSS (NGSS Lead States, 2013), the 4DEE Framework (Berkowitz et al., 2018), and the K–12 Environmental Education: Guidelines for Excellence (NAAEE, 2019) that connect to permaculture principles and design**.** This appendix is not intended to be an exhaustive list, but rather it highlights the breadth of possibilities and connections within permaculture-based education.

Methods

This study investigated preservice teacher (PST) ideas about permaculture and views toward teaching permaculture after participating in a focused, small-scale instructional intervention on the topic as part of their elementary science methods course. This study was designed as an exploratory study to provide a basis for further interventions in permaculture-integrated elementary science classrooms. We applied a mixed-methods design (Creswell & Plano Clark, 2011) to collect and triangulate data from paired pre/post-tests, an in-class lesson analysis activity, and the PSTs' daily end-of-class reflection. The following two research questions (RQ) guided the design of this study:

- RQ1: What do preservice elementary teachers self-report about their understanding of permaculture topics, and how is this impacted by participating in permaculture-focused teacher training?
- RQ2: What are preservice teacher views about teaching permaculture in the classroom?
    - How does participating in permaculture-focused teacher training impact preservice teachers' views on teaching permaculture?

Participants

Twenty-two PSTs enrolled in one section of an elementary science methods course at a large public university in the southwest participated in this study. This represented the full enrollment of the course section. All participants were either EC-6/ESL majors, EC-6/Bilingual majors, or K-12 SPED majors, and all used she/her/hers pronouns. Twenty (91%) were 18-to-24 years old, and two (9%) were 35-to-44 years old.

Study Context

This study was embedded within the routines of an elementary science methods course that met once a week for three hours each class session. The course, which was taught by the second author, introduced common reform-oriented approaches to inquiry-based elementary science teaching and learning, with an emphasis on the 5E instructional model. The main instructional intervention for this study took place during week eight of the course. Previous week's topics included the nature of science; positioning students as scientists; the engage, explore, explain, elaborate, and evaluation phases of the 5E model; and interdisciplinary learning. The week eight class session was divided between the permaculture intervention (first 1.5 hours) and an exploration of formative assessment strategies (second 1.5 hours).

Design of the Permaculture Intervention

The permaculture intervention in the course included four components: background permaculture readings and videos, guided discussion, food forest design activity, and lesson plan analysis activity. We designed these components to engage PSTs both as current science learners and as future science teachers of permaculture.

Background Permaculture Readings and Videos

As part of their out-of-class preparation for the week, PSTs were given links to one reading and four short online videos related to permaculture. Collectively, these background materials targeted both PSTs' content knowledge and their pedagogical knowledge for permaculture. The videos defined permaculture, introduced its core principles, explained the design of a food forest, and positioned permaculture as a potential answer to issues of desertification (Discover Permaculture with Geoff Lawton, 2019; Oregon State University Ecampus, 2016a, 2016b). We selected these videos because they introduced permaculture using language that was accessible to novices and illustrated it using practical examples of how permaculture can help solve ongoing environmental problems. The reading highlighted the benefits and challenges of teaching permaculture to young children (Permaculture Association, 2017) and was selected because it modeled ways to bring permaculture into a school setting. As part of the normal weekly course routine, we gave the PSTs a reading guide that included guiding thinking prompts to assist with individual reflection and prepare for in-class discussion.

Guided Discussion

The in-class portion of the permaculture intervention began with a 20-minute guided discussion of the out-of-class videos and reading. We asked PSTs to share what they had learned about permaculture, its environmental significance, and its application in food forest design. We then transitioned into a deeper discussion of the different plants that might be found in a food forest. This discussion connected PSTs' ideas about plants and their needs to a pictorial illustration of the seven layers of a food forest and detailed how each layer supported the overall food forest. Across the discussion, we emphasized how permaculture-based gardens such as food forests leverage biodiversity to enhance the stability of the system and use purposeful design to meet the needs of individual plants.

Food Forest Design Activity

After finishing the discussion, the class divided into small groups of 4-5 PSTs to design their food forests. Each small group was given a list of 34 different regional plants, pictures of each plant, and a large poster board that represented their food forest plots and was labeled with the cardinal directions. The plant list was purposively designed to include plants from all layers in a typical food forest and included information about each plant's height and sun requirements. (Note: For a more complex instructional intervention, this list could also include information about each plant's water requirements.)

The PSTs were instructed to draw a model of how the sun would move across the food forest plot, select a variety of plants to include in their food forest, and then paste the picture of each plant into an appropriate place in the food forest plot. After this, each PST wrote an explanation for one of the plants in their food forest. This explanation detailed why they chose to put that particular plant in that particular place in their food forest design. At the end of the activity, each small group shared their food forest design with the rest of the class and highlighted key decision points in their design process. The full food forest design activity lasted 40 minutes.

Lesson Analysis Activity

As the final in-class instructional activity, PSTs worked in small groups to analyze the Texas K-6 science standards (TEKS) supported by various lesson plans on permaculture and to determine whether they would use these lessons in their classrooms. We selected these lesson plans to represent the types of resources that teachers might find online if they searched for support in developing a lesson on permaculture. Each of the six lesson plans (Alabama Outdoor Classroom, n.d.; School Garden Project of Lane County, 2016a, 2016b; Speilmaker, n.d.; Whole Kids Foundation and American Heart Association, n.d.) was freely available online, consistent with key elements of permaculture education, developed by reputable sources, and applicable to elementary contexts. Each small group spent 20 minutes reading and analyzing two of the six lessons. For each lesson, the group recorded which science TEKS - if any – aligned with the lesson activities and justified whether they would choose to use the lesson activities in an elementary science classroom. After completing the analysis, each small group briefly shared the results of their analysis with the whole class.

Data Collection and Analysis

This study triangulates data from paired pre/post-tests, an in-class lesson analysis activity, and the PSTs' daily end-of-class reflection to answer both research questions.

Pre/post-test

We adapted Wiman's (2016) questionnaire about classroom school gardens to target permaculture topics and used this redesigned instrument to capture PSTs' self-reported understanding of permaculture topics and confidence about teaching science and permaculture, as well as select demographic information. The questions on the pre/post-test used an 11-point Likert scale ranging from strongly disagree (0) to strongly agree (10). Appendix A includes the pre/post-test questions used in this study. PSTs individually completed the pre-test in class the week before the permaculture intervention and the post-test the week following the intervention. To analyze this data, we converted the PST's responses from the original 0 to 10 scale to a new scale from -5 to 5, with the neutral mid-point at 0. In this new scale, negative values can be interpreted as being on the disagree side and positive values on the agree side. We used a two-tailed paired samples t-test in SPSS to compare PST pre/post-test responses and calculated effect size using Cohen's d.

Lesson Analysis Activity

We collected the worksheets that the PSTs completed as part of the in-class lesson analysis activity and analyzed these for (1) the specific state standards that PSTs selected to align with each lesson plan and (2) the justifications the PSTs used when deciding whether to use these lesson plans. The PSTs worked in small groups of 4-5 for this activity. Some groups ended up approaching the written portion of this activity by notating a summary group response while the PSTs in other groups notated responses individually. Because of this, we coded the lesson analysis activity at the small group level (n=5) instead of the individual PST level (n=22). We descriptively analyzed the standards PSTs selected for their grade level, a domain of science (life science, earth science, etc.), and the inclusion of permaculture topics. We analyzed the justifications that the PSTs wrote using descriptive, inductive coding and the constant comparative method (Saldaña, 2016; Strauss & Corbin, 1990). The first author coded this data to categorize themes in the justifications and organized these themes based on whether they captured reasons for using the lesson plan (advantages) or reasons for not using the lesson plan (disadvantages). The second author reviewed this coding, and the final codes were established through discussions between the two researchers.

Daily Reflections

As part of a reflection routine previously established by the science methods instructor, PSTs wrote a short reflection about the personal impact of the day's activities at the end of each class meeting. For this reflection, PSTs would write about a "Turn your Head" moment (something they think differently about or have learned), a "Turn your Heart" moment (something they feel differently about or have come to value), and/or a "Turn your Hands" moment (something they will do differently or give more emphasis to). PSTs could choose to write about one, two, or all three types of moments and could focus on any aspect of the class meeting. For this study, we collected and analyzed PSTs' daily reflections for week seven of the science methods course. As week seven included both the permaculture intervention and an exploration of formative assessment strategies, PSTs could choose to write about the permaculture intervention, the formative assessment exploration, or both depending on what they perceived as most impactful from that class period. As with the lesson plan analysis, we analyzed the PST daily reflections using descriptive, inductive coding and the constant comparative method (Saldaña, 2016; Strauss & Corbin, 1990). The first author coded this data to categorize (1) themes in the permaculture topics referenced by the PSTs in their reflections and (2) themes in statements the PSTs made related to teaching permaculture. The second author reviewed this coding, and the final codes were established through multiple rounds of discussion.

Results

The following analysis presents the study findings in sections aligned with each research question. Each section triangulates data from the pre/post-test, lesson plan analysis, and daily reflection.

RQ1: Preservice Teacher Knowledge and Application of Permaculture Topics

Pre/post-test

PSTs individually self-reported their perceived level of understanding of nine topics related to permaculture using an 11-point Likert scale ranging from "none" to "expert" on a pre-test taken the class before the permaculture intervention and a post-test taken the class after the intervention (Table 1). On the pre-test, PSTs reported low levels (mean < -1) of initial knowledge about food forests, biodiversity, and microorganisms; medium levels (-1 < mean < 1) of initial knowledge about soil and patterns in nature; and high levels (mean > 1) of initial knowledge of climate, plants and their needs, interactions of living organisms, and animals and their needs.

Table 1.

T-test results on PST self-reported understanding of permaculture topics

Permaculture Topics	Pre Mean	Post Mean	Mean Differences *(SD)*	*t* (Sig. 2-tailed)	Cohen's d
Food Forest	-2.59	2.09	4.68 (2.77)	7.94 (<.001*)	1.68
Biodiversity	-1.41	1.27	2.68 (2.57)	4.89 (<.001*)	1.04
Microorganisms	-1.14	1.18	2.32 (1.81)	6.01 (<.001*)	1.28
Soil	0.09	2.00	1.91 (2.60)	3.45 (.002*)	0.73
Pattern in nature	0.41	1.36	0.95 (2.46)	1.82 (.083)	0.38
Plants and their needs	1.64	2.55	0.91 (2.58)	1.65 (.113)	0.35
Interaction of organisms	1.68	2.55	0.87 (2.14)	1.89 (.073)	0.40
Animals and their needs	2.64	2.73	0.09 (1.85)	0.23 (.820)	0.04
Climate	1.55	1.64	0.09 (1.74)	0.24 (.809)	0.05

*N = 22, p < 0.01**

On the post-test, PSTs reported higher levels, on average, of knowledge for all nine topics. These increases in mean scores ranged from 0.09 points (climate and animals and their needs) to 4.68 points (food forests). A two-tailed paired t-test revealed statistically significant increases ($p < 0.01$) in knowledge about food forests, biodiversity, microorganisms, and soil. Calculation of Cohen's d for these topics indicated a large effect size for food forests, biodiversity, and microorganisms with $d > 0.80$ and a medium effect size for soil with $d > 0.50$. Each of these topics was highlighted in multiple instructional activities in the permaculture intervention.

Mean increases in knowledge about patterns in nature, plants and their needs, interactions of living organisms, animals and their needs, and climate were not statistically significant. As PSTs reported higher average levels of initial knowledge for many of these topics (e.g., animals and their needs) this lack of statistically significant change may be due to a ceiling effect in PST self-reporting. In addition, some of these topics (e.g., climate), were only tangentially referenced in the permaculture intervention.

The PSTs were also asked on the pre/post-test to select a definition of permaculture from a multiple-choice list. On the pre-test, nine of the 22 PSTs (41%) correctly chose "consciously designed landscapes which mimic the patterns and relationships found in nature, while yielding an abundance of food, fiber, and energy for provision of local needs." On the post-test, this doubled to 18 of the 22 PSTs (82%) selecting the correct definition.

Lesson Plan Analysis

Each of the five groups of PSTs collectively analyzed two publicly available lesson plans on topics related to permaculture and identified how the learning opportunities within each lesson plan best aligned with one of the K-6 Texas science standards (TEKS). The PST groups identified eight unique science standards from 1st through 5th grades (Table 2). These standards focused on traditional life science and earth science topics. Each group selected a different standard for each of the two lessons they analyzed, and in cases where two groups analyzed the same lesson, each group selected different standards. All of the standards selected by the PSTs aligned with the permaculture topics included in the lesson plans.

Table 2. State science standards selected by PST groups during lesson analysis activity

Lesson Plan	Content Foci of Lesson Plan	PST Group	Grade Level and Texas Science Standard (TEKS) Selected by PST Groups for each Lesson Plan
A - Forest floor investigation (Alabama Outdoor Classroom, n.d.)	Organisms that live in and under the leaf litter, including decomposers	1	1st grade Earth & Space 1.7A - The student is expected to observe, compare, describe, and sort components of soil by size, texture, and color.
		2	5th grade Organisms & Environment 5.9A - The student is expected to observe the way organisms live and survive in their ecosystem by interacting with the living and nonliving components.
B - Planting the summer garden (School Garden Project of Lane County, 2016b)	Seasonality of plants in connection to their climate	1	3rd grade Organisms & Environment 3.10B – The student is expected to investigate and compare how animals and plants undergo a series of orderly changes in their diverse life cycles such as tomato plants, frogs, and lady beetles.
		5	5th grade Organisms & Environment 5.9A – (see 5.9A above)
C – Composting (WKF & AHA, n.d.)	Creating a class compost bin for the garden	4	5th grade Organisms & Environment 5.9B - The student is expected to describe the flow of energy within a food web, including the roles of the Sun, producers, consumers, and decomposers.
D - Garden habitat (School Garden Project of Lane County, 2016a)	Importance of food, water and shelter; and the different needs of organisms	3	1st grade Organisms & Environment 1.9B - Analyze and record examples of interdependence found in various situations such as terrariums and aquariums or pet and caregiver.
		5	5th grade Organisms & Environment 5.9B – (see 5.9B above)
E - Soil types by texture (Speilmaker, n.d.)	Determining the texture of soil samples	2	4th grade Earth & Space 4.7A - The student is expected to examine properties of soils, including color and texture, capacity to retain water, and ability to support the growth of plants.
F - Seed packets (WKF & AHA, n.d.)	Gathering information from seed packets about plant growth and needs	3	2nd grade Organisms & Environment 2.9B - The student is expected to identify factors in the environment, including temperature and precipitation, that affect growth and behavior such as migration, hibernation, and dormancy of living things.
		4	2nd grade Organisms & Environment 2.9A - The student is expected to identify the basic needs of plants and animals.

Daily Reflection

Fourteen of the 22 PSTs (64%) spontaneously mentioned one or more topics related to the permaculture intervention in their individual end-of-class daily reflections. Half of these reflections (7 PSTs) referred only to permaculture in general. For example, a PST wrote, "I learned what permaculture is and how to incorporate it in the classroom." Another explained, "I value the permaculture. It brings community to the school." Five PSTs referenced permaculture in conjunction with gardening, and two reflected solely on gardening. For example, a PST wrote, "We will be doing a class garden." In addition, food forests and compost were each specifically mentioned once by PSTs.

RQ2: Pre-service Teacher Views about Teaching Permaculture in the Classroom

Pre/post-test

PSTs individually self-reported their perceived ability on four items related to teaching science using an 11-point Likert scale ranging from "strongly disagree" to "strongly agree" on a pre-test taken the class before the permaculture intervention and a post-test taken the class after the intervention (Table 3). On the pre-test, PSTs reported no low levels (mean < -1) for any item; medium levels (-1 < mean < 1) of ability on teaching science concepts effectively, understanding the NGSS, and finding better ways to teach than traditional lessons, and high levels (mean > 1) of initial ability on understanding the TEKS, which are the state science standards for Texas.

On the post-test, PSTs reported higher levels, on average, of knowledge for all four topics: teaching science concepts effectively, understanding the NGSS, finding better ways to teach than traditional lessons, and understanding the TEKS. These increases in mean scores ranged from 0.05 points (using school gardens) to 2.09 points (teaching science concepts effectively). A two-tailed paired t-test revealed the increases for all topics were statistically significant ($p < 0.01$). Calculation of Cohen's d indicated a large effect size with $d > 0.80$ for all topics.

Table 3.

T-test results on PST self-reported ability to teach science

Ideas about Science Teaching	Pre Mean	Post Mean	Mean Differences *(SD)*	*t* (Sig. 2-tailed)	Cohen's d
I can teach science concepts effectively	-0.23	1.86	2.09 (1.85)	5.30 (<.001*)	1.12
I know and understand the NGSS for science curriculum	-0.91	0.91	1.82 (1.56)	5.46 (.<.001*)	1.16
I know and understand TEKS for science curriculum	1.36	3.00	1.64 (1.87)	4.11 (<.001*)	0.87
I can find better ways to teach elementary science than traditionally taught	0.86	2.50	1.64 (1.89)	4.06 (.001*)	0.86

*N = 22, p < 0.01**

The pre/post-test also asked PSTs if they would use a school garden to implement a science curriculum if they knew how. On the pre-test, 21 (95%) of the PSTs indicated that they would like to use a garden. Only one PST indicated that they would not. This PST was concerned about the time required and about not having enough knowledge about gardening. On the post-test, all 22 of the PSTs indicated that they would like to use a garden to implement a science curriculum. When asked the reasons for this, most PSTs indicated that they have an interest in gardening with students (n=15 pre-test, n=16 post-test) and know how gardening aligns with science curricula (n=12 pre-test, n=16 post-test). Only about a quarter of PSTs indicated that they thought they would have enough time to spend in the garden with students (n=6 pre-test, n=6 post-test), have the resources (n=6 pre-test, n=4 post-test), or have enough knowledge to do gardening activities (n=5 pre-test, n=7 post-test).

Lesson Plan Analysis

In the lesson plan analysis activity, the five PST groups were asked to justify why they would or would not use the lesson in their classroom. Seven themes were identified through the coding of these rationales. We classified three of these themes as advantages or reasons why PSTs would use the lesson in their classroom: provides active (hands-on) learning experience, provides real-life learning experience, and is environmentally conscious. We classified an additional three themes as disadvantages or reasons why PSTs would not use the lesson in their classroom: cost of the budget, time required, and general difficulty. Finally, two themes - developmental appropriateness of lesson and spatial resources required – were positioned by PSTs as both advantages and disadvantages of the lessons. Table 4 shows which rationales each PST group used to justify their inclusion or exclusion of each lesson plan.

Table 4.

PST rationales for using lesson plans in their future classrooms

PST Group	Advantage			Advantage (+) or Disadvantage (-)		Disadvantage		
	Active learning	Real life experience	Environ-mental focus	Developmental appropriateness	Spatial Resources	Cost	Time	General difficulty
1	A* B			A (+)	A (+/-)		B	
2	A E			A (+/-)	A (+)		E	
3	D F	D						
4		C F	C	C (-)				C
5	B D	B D			B (-)	B		
Total n=10	8	5	1	3	3	1	2	1

**A = Lesson A, B = Lesson B, etc.*

Advantages. The most frequently mentioned advantage of using permaculture to teach science was the ability to incorporate ***active*** or ***hands-on learning*** into the classroom. Four of the five PST groups mentioned this theme, and each group did so for both the lessons they analyzed. For example, PST Group 5 categorized Lesson Plan D as allowing "every student to participate within the activity and make connections" as they explore the garden habitat. PSTs routinely described the active learning supported by the lesson plans as being interactive, informative, engaging, and fun.

Three PST groups highlighted the ***real-life experiences*** that Lesson Plans B, C, D, and F provided for students. These lessons focused on gardening and composting. For example, as part of Lesson Plan B, students plant summer crops and investigate differences in the lifecycles of cool- and warm-season crops. Interestingly, the only PST group to not mention active learning in the lessons wrote extensively about the real-life experiences in the two lesson plans they analyzed. So, collectively either *active learning* or *real-life experiences* were highlighted by every PST group in their analysis of each lesson plan.

Finally, PST Group 4 highlighted how Lesson Plan C taught about ***environmental conservation*** and environmentally conscious ways of living. This was the only time this advantage was explicitly stated by the PSTs in the lesson analysis. Lesson Plan C was also the only lesson plan to explicitly focus on composting.

Disadvantages. Four of the five PST groups highlighted the drawbacks of the lesson plans in their analysis. Two groups positioned the amount of ***time*** needed to complete the activities as a disadvantage of the lesson plans. PST Group 1 described how Lesson Plan B, as written, would require students to be in the garden for a full semester or year, and PST Group 2 thought that the beginning part of Lesson Plan E was time-consuming as students were required to wait for the dirt to settle before continuing to other parts of the activity. However, both groups suggested adaptations to the lesson activities that would make more efficient use of time and thereby minimize the impacts of this disadvantage. One group (PST Group 5) questioned whether they would have the ***budget*** to purchase all the plants required for the gardening activities in Lesson Plan B. In addition, PST Group 4 wrote how Lesson Plan C would be ***generally difficult*** as "compost bins are hard to take care of."

Mixed Advantage and Disadvantage. Two themes were highlighted by some PSTs as providing an advantage and by others as providing a disadvantage in the lesson: ***developmental appropriateness*** and ***spatial resources required.*** Three PST groups focused on whether the lessons included developmentally appropriate activities. PST Groups 1 and 2 had a split decision on Lesson Plan A, which includes an investigation of the variety of organisms on a forest floor. Group 2 and some members of Group 1 thought that a strength of this plan was that it could be adapted to be used across all elementary grades, including K-2 students. For example, Group 2 wrote, "The hula-hoop idea [in the lesson] is great because it can be applied to any grade - showing them the living things on the ground within the hula hoop". However, other members of Group 1 thought that the same lesson would not be suitable for younger students. Similarly, Group 4 did not view Lesson Plan C, which focused on compost, as suitable for young students.

Three PST groups highlighted the ***required spatial resources*** needed to enact the lessons. Two groups questioned whether they would have access to the types of environments listed in the lessons. PST Group 5 questioned whether they would be able to find enough space at the school to grow the different plants required by Lesson Plan B. Similarly, PST Group 1 noted that Lesson A called for students to explore two different specific environments as part of the lesson activities and questioned whether these environments would be represented in the accessible space around the school. Once again, Lesson Plan A provoked a split decision as PST Group 2 and some of PST Group 1 thought that a strength of the lesson activities was that they could be done almost anywhere on the school grounds.

Daily Reflections

Twelve of the 22 PSTs (55%) spontaneously mentioned issues related to teaching permaculture in their individual end-of-class daily reflections. One PST described how they learned more about how to teach permaculture. Two explained that it is something that they would give more emphasis to in their classroom. However, the majority (10 PSTs) of these reflections focused on the general or specific benefits that PSTs saw in integrating permaculture in their classrooms. Specific benefits focused on by the PSTs included providing an active learning environment (2 PSTs), building classroom/school community (2

PSTs), supporting advanced learning (1 PST), integrating multiple learning standards (1 PST), and promoting environmental awareness (4 PSTs). For example, one PST wrote, "Educating students about permaculture is important for the future of our environment and sustainability." Another explained, "I love the idea of permaculture in the classroom. It can cover so many of the TEKS and is very hands-on. It provides another classroom for you to use."

Discussion

Permaculture: A Unifying Context for Integrated Learning

Elementary teachers have a history of using school gardens as a practical context to integrate and unify the teaching and learning of science concepts (Graham et al., 2004; Graham & Zidenberg-Cherr, 2005). This study supports the literature about school gardens and science by highlighting the potential of permaculture to be a unifying context for integrating elementary learning across the various science domains. Although science education standards such as the NGSS often present the domains of science as distinct, these standards also emphasize that contemporary scientists work in interdisciplinary teams that cross the historical boundaries of these domains (NGSS Lead States, 2013). Practices such as designing, building, and observing a food forest in a school permaculture garden require fluency in the cross-cutting concepts of science and disciplinary core ideas in both life and earth/geosciences: patterns in nature, biodiversity, interaction of living organisms, soil, and weather. Many traditional garden-based elementary learning activities focus primarily on students learning about life science topics (e.g., Rye et al., 2012). In contrast, permaculture-based activities can also support learning about earth science topics and systems thinking, since permaculture designs use a self-sustaining system rather than human inputs to meet plant needs (Lewis et al., 2008).

In this study, PSTs self-reported significant increases in their understanding of both life science (e.g., microorganisms, biodiversity) and earth/geoscience topics (e.g., soil) after participating in permaculture activities. PSTs also drew upon both life science and earth science standards in their critiques of permaculture-related lesson activities. Elementary teachers often report being less prepared to teach earth science than life science (Trygstad, 2013). Integrating permaculture into PST preparation programs could be one way to address this deficiency. However, we caution teacher educators against artificially positioning permaculture-based gardens as a cure-all for addressing all elementary science learning. Subramaniam et al. (2018) found that novice PSTs often design outdoor investigations that lack clear opportunities for students to develop the specific evidence-based explanations that the lesson was supposed to target. PSTs will likely need support to tease apart when permaculture-based gardens could be used as the full setting for student investigations and when gardens would best be used as an anchoring phenomenon to launch classroom-based activities.

Benefits of Permaculture Education

The PSTs in this study positioned permaculture-based instructional activities to provide elementary students with a hands-on inquiry learning experience situated in an authentic, real-life context that promotes environmental awareness. These PST views align with research about elementary student learning that highlights how garden-based activities promote student sustainability thinking, environmental conservation, and science learning (Lebo & Eames, 2015; Lewis et al., 2008). Most PSTs also viewed permaculture activities as developmentally appropriate for elementary classrooms and a useful context for providing students of all grade levels with interactive real-world experiences. These findings are consistent with prior research with preservice and in-service teachers and gardening (Blair, 2009; Eick, 2012; Kelley & Williams, 2013; Trauth-Nare, 2015; Wilson et al., 2015).

Barriers to Permaculture Education

Previous research has detailed many common barriers to implementing gardening-based learning activities in schools, including limited resources (time, funding, and space), lack of teachers' interest and experience, and few curricular materials connected to academic standards (Burt et al., 2018; Graham & Zidenberg-Cherr, 2005; Smith et al., 2019). The results of this study both confirmed and countered these previous findings. The PSTs did view limited resources – specifically time, funding, and space – as a significant disadvantage to implementing permaculture-based learning activities in their future classrooms. These are systemic issues that individual teachers have relatively little control over and which likely need to be addressed at the district or school level. However, in contrast to previous studies, the PSTs in this study reported that they had an interest in implementing gardening activities with their future students, knew how gardening aligns with elementary science standards and curriculum and would be able to find curricular materials to implement permaculture activities in their classrooms. Teachers in previous studies had positioned these same elements as barriers to using school gardens in their classrooms (Blair, 2009; Graham & Zidenberg-Cherr, 2005). The findings from this study suggest that exposure to permaculture as part of preservice teacher training or professional development might help remove these barriers for individual teachers.

Plants and Their Needs: A Starting Point for Permaculture in Elementary Science

In this study, PSTs' self-reported understanding of plants and their needs did not significantly increase following the permaculture intervention. This could be due to a ceiling effect of PSTs' relatively high initial understanding of plants. Plant structure, functions, and needs are common disciplinary core ideas in elementary life science (NGSS Lead States, 2013), and most elementary teachers report feeling well-prepared to teach life science (Trygstad, 2013). As elementary PSTs appear fairly familiar with this topic, plants and their needs might prove a useful starting point (as opposed to a targeted learning outcome) for exploring permaculture-based learning activities. The food forest design activity in this study supports PSTs in thinking about plants and their needs in a unique way that emphasizes interactions between plants and the use of resources within a system while allowing them to draw on prior knowledge about how individual plants meet their basic needs. This integration of a new idea – permaculture – within the context of a familiar science topic – plants – might have contributed to some of the positive findings of this study. Educators know that effective science learning environments build off prior experiences to scaffold new learning (NGSS Lead States, 2013). We suggest that explorations of plants and their needs might be a gateway for bringing permaculture education into more elementary science classrooms.

Limitations

We recognize that the exploratory nature of this pilot study gives rise to many limitations. First, the study focused on a small sample of 22 PSTs from the same university taking the same elementary science methods course. Many of the aspects of this local context, including other topics covered in the course and the pedagogical approaches of the course instructor, likely impacted how the PSTs responded to the permaculture intervention. Because of this, any generalization of the study should be done with caution. Second, the study presents the first iteration of the instructional activities and study measures. Both of these would benefit from further refinement and revision in future research. One small-scale refinement would be to use scaled three-dimensional models of plants instead of using two-dimensional pictures to construct the food forests so that PSTs could better explore spatial resources and shadows in their designs. Future iterations could also explicitly include more of the social and ethical dimensions of permaculture in the instructional intervention. Third, although this study examines PST self-reports of what they understand and could do, it does not capture how PSTs will actually teach or the impact of that instruction on students. However, this is a common limitation of much of the research conducted in teacher preparation programs.

Implications and Future Directions

This study offers insights into how science teacher educators might integrate permaculture into elementary teacher preparation and builds upon the limited prior research on permaculture in elementary schools (Lewis et al., 2008; Morgan, 2017; Praetorius, 2006). Holistic environmental education topics such as permaculture can serve as a practical context in which to integrate science concepts, practices, and cross-cutting concepts in elementary teacher preparation programs. This study used instructional activities designed for elementary students as a tool for engaging PSTs in permaculture activities and as a resource for expanding PSTs' exposure to freely available curricula. In critiquing these curricula, PSTs themselves highlighted how gardens have the potential to provide students with active learning experiences that promote environmental awareness and connect to daily life. These are fundamental elements of high-quality elementary science education (National Research Council, 2012).

As seen in this and prior research, many of the perceived barriers to permaculture-based gardening focus on the practical aspects of creating and maintaining a garden. Science teacher educators could consider moving beyond the in-class explorations of permaculture featured in this study and collaborate with colleagues in schools of agriculture to create small-scale food forests on college campuses. These permaculture "teaching gardens" could supply anchoring experiences for PSTs to develop their disciplinary knowledge and practice and help PSTs develop the confidence to initiate permaculture activities in their future schools. Tal and Morag (2009) suggest having persistent pedagogical impacts, PSTs will likely need extended support in implementing outdoor learning such as gardening. However, PSTs who participate in gardening activities with students as part of their teacher training highlight how the experience helps PSTs connect to elementary students' strengths – their curiosity, funds of knowledge, and potential for success in science (Trauth-Nare, 2015; Wilson et al., 2015).

Future research could also examine how other integrated topics from sustainability and environmental education, such as carbon footprints or closed-loop product design, could also be used to improve elementary teacher preparation. Although these topics cross the boundaries of traditional scientific disciplines, they align with many state and national standards (NGSS Lead States, 2013) and could be effectively explored within standards-based elementary classrooms. As sustainability topics such as permaculture integrate science ideas and societal concerns, these topics could be used to design curricular units that highlight socio-scientific issues (Hancock et al., 2019) and promote equity and social justice in science education (Luna et al., 2018).

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Appendix A. National standards connected to permaculture principles and design

NGSS (NGSS Lead States, 2013)	4DEE Framework (Berkowitz et al., 2018)	K–12 Environmental Education: Guidelines for Excellence (NAEEE, 2019)
Student Performance Expectations - K-ESS3-3 Communicate solutions that will reduce the impact of humans on the land, water, air, and/or other living things in the local environment. - 3-ESS2-1 Represent data in tables and graphical displays to describe typical weather conditions expected during a particular season. - 5-ESS3-1 Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment. - 3-5-ETS1-1 Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost. Understandings about the Nature of Science - Science is a human endeavor Influence of Engineering, Technology, and Science on Society and the Natural World - 6-8 Connection: All human activity natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment	Core Ecological Concepts - Organisms: Abiotic and biotic features of the environment, Resources and regulators, Habitat and niche - Ecosystems: Nutrient cycling Ecology Practices - Working collaboratively - Communicating and applying ecology Human-Environment Interactions - Human dependence on the environment: Ecosystem Services - How humans shape and manage resources/ecosystems/the environment - Ethical dimensions: Sustainability as a normative, socially constructed, aspirational goal; Environmental justice; Ecological economics Cross-Cutting Themes - Structure & function - Spatial & temporal: Scales, Stability & change	Strand 1: Questioning, Analysis, and Interpretation Skills Strand 2: Environmental Processes and Systems - 2.2 Human systems o A. Individuals, groups, and societies o B. Culture o D. Economic systems - 2.3 Environment and society o A. Human-environment interactions o B. Resource distribution and consumption Strand 3: Skills for Understanding and Addressing - 3.1 Skills for analyzing and investigating environmental issues: o B. Sorting out the consequences of issues o D. Working with flexibility, creativity, and openness - 3.2 Decision-making and action skills Strand 4: Personal and Civic Responsibility

Appendix B. Pre/post-test questions

Questions 1-4. Rate from Strongly Disagree (0) to Strongly Agree (10)

1. I know and understand the NGSS for science curriculum
2. I know and understand TEKS for science curriculum
3. I can teach science concepts effectively
4. I can find better ways to teach elementary science than traditionally taught

Question 5. (Yes/No) If you knew how, would you like to use school garden to implement science curriculum?

5b. If you selected no, select the following reason or reasons

- Don't have enough time to spend in the garden with students
- Don't have enough knowledge to do gardening activities
- Don't have interest work in gardening with students
- Don't see how gardening aligns with science curriculum or science standards
- Don't have the resources

5c. If you selected yes, select the following reason or reasons

- Have interest work in gardening with students
- Have enough time to spend in the garden with students
- Know how gardening aligns with science curriculum or science standards
- Have the resources
- Have enough knowledge to do gardening activities

Questions 6-14. Rate understanding from None (0) to Expert (10)

6. Biodiversity
7. Food Forest
8. Microorganisms
9. Soil
10. Pattern in nature
11. Interaction of organisms
12. Plant and their needs
13. Animals and their needs
14. Climate

Question 15. Permaculture is

A) the study of insects, including related arthropods
B) the art and science of cultivating the soil, growing crops and raising livestock
C) consciously designed landscapes which mimic the patterns and relationships found in nature, while yielding an abundance of food, fiber, and energy for provision of local needs.
D) the art and science of growing and handling fruits, nuts, vegetables, herbs, flowers, foliage plants, woody ornamentals, and turf.