High School Students' Motivation Regarding an Integrated STEM Food System Project

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Abstract

High school students need to be prepared for post-secondary education and enter the workforce to solve real-world problems including food and energy sustainability. Real-world problems require students to apply critical thinking and problem-solving skills and transfer their learning across disciplines. Framed as a grand challenge to students, the food systems project utilized an integrated STEM approach complemented with a systems thinking approach that challenged students to analyze relationships among system components with a holistic perspective. This quantitative descriptive study described the perceptions, experiences, and career interests of high school students who completed a food systems STEM project. The students self-reported they were interested in the project, applied scientific reasoning to solve the problem, and collaborated with peers to apply STEM concepts. Students also reported the project helped them learn more about STEM careers and reported higher interest in career fields such as science, technology / engineering, the agricultural industry, food industry, and natural resources industry after completing the food system STEM project. Food systems integrated STEM projects can be a tool to engage students to solve complex problems and build interest in STEM careers.

Keywords: project-based learning, food systems, integrated STEM education, high school, motivation

People in society face complex grand challenges that affect the global population, and these complex problems can be solved with a variety of solutions (Nowell et al., 2020). High school students will face grand challenges such as food and energy sustainability as consumers and professionals in the workforce (Hernandez-Aguilera et al., 2021; Nowell et al., 2020; FAO et al., 2020; Rosegrant & Cline, 2003). High school students need to be able to solve real-world problems to be prepared for the workforce (Easterly et al., 2017). Career and technical education (CTE) prepares secondary education students to apply academic content and essential career skills to prepare for future careers and the workforce (Karmel, 2010) and integrating science, technology, engineering and mathematics (STEM) in CTE can help prepare high school students to collaborate across disciplines, solve complex problems, and the analyze problems using different perspectives to better understand a grand challenge (McKim et al., 2017; Nowell et al., 2020; Wang & Knobloch, 2023). As a means to test the students' ability to solve complex problems, a grant-funded project leveraged integrated STEM (iSTEM) education that used agro-ecosystem thinking within an agricultural design challenge to develop and practice evidence-based decision making. Evidence-based decision-making is argumentation based on a claim that is supported with evidence and uses reasoning from multiple disciplines to justify a decision to support a design solution (Rebello et al., 2020).

It is important to engage high school students in solving complex problems because there is a need prepare students in the U.S. to meet the demand for careers in STEM and agriculture, food, and natural resources (AFNR) (Fernandez et al., 2020; National Institute of Food and Agriculture United States Department of Agriculture, 2024). According to Johnson et al. (2020) and the National Science and Technology Council (2018), STEM skills and literacy development should begin in elementary and secondary schools to best prepare students for not only post-secondary education but also trade careers. Teaching STEM with an integrated approach helps students to develop systems thinking skills and transfer their knowledge across disciplines (Wang & Knobloch, 2023). One of the objectives of the grant-funded project was to equip high school students with critical thinking and problem-solving skills that are essential to success in the 21st-century workforce (Dym et al., 2005). Colleges of agriculture play an important role as land-grant universities in engaging with K-12 audiences (Swan & DeLay, 2014; Thies et al., 2023) and strengthen academic and career connections through innovative curricula, teacher professional development, and interactions with scientists (Cotton et al., 2009; National Academy of Sciences, 2009).

Project-based learning is a constructivist teaching method that engages students to solve authentic problems and make decisions using inquiry-based and design-based learning (Kokotsaki et al., 2016). Utilizing project-based learning (PBL), educators can present their students with a grand challenge or driving question to frame a real-world problem (Nagarajan & Overton, 2019; Wang & Knobloch, 2018, 2022). Real-world problems are complex and require students to think holistically, or with a systems thinking approach. Systems thinking develops student skills that can be transferred to the workforce (Nagarajan & Overton, 2019). An iSTEM approach complements systems thinking and interdisciplinary learning (Wang & Knobloch, 2023).

Integrated STEM “intentionally and purposively blend[s] multiple disciplines (i.e., academic and vocational) to help students meaningfully learn and apply academic content through real-world problems framed in designed complex systems and grounded in career and technical contexts that facilitate multidisciplinary, interdisciplinary, or transdisciplinary learning for the development of life-long and workforce development connections and skills” (Wang & Knobloch, 2023, p. 253). STEM integration occurs at different levels (Wang & Knobloch, 2018, 2022) and the implementation is often related to the educator’s knowledge and ability (Kelley & Knowles, 2016). STEM is commonly taught with a focus on science and mathematics and excluding technology and engineering or not fully integrating them. STEM is often only integrated within STEM domains, but other disciplines outside of STEM can be used to contextualize content such as agriculture, food, and natural resources (Kelley & Knowles, 2016; Moore et al., 2020; Peacock, 2007; Wang & Knobloch, 2020; Wang et al., 2020). Opinions about when and how to integrate STEM content varies. Some researchers support the integration of the content areas early on and others support building a single discipline foundational knowledge with integration to follow (Moore et al., 2020; Kelley & Knowles, 2016).

Systems thinking fits under the skill of critical thinking in Battelle’s (2019) 21st century skills framework. Students who demonstrate systems thinking are able to see a problem holistically, identify more possible causes of the problem, and solve the problem with various systems in mind (Arnold & Wade, 2017; Hiller Connell et al., 2012; Meadows, 2008). Contextualizing systems thinking in the food systems context is an ability to see the interacting components of a whole food system and understand the complexities and dynamics of the components of the system (Charoenmuang, 2020; Kasser, 2018; Lee et al., 2017). Food systems thinking is important to: (1) solve complex global challenges (Flynn et al., 2019) in the field of STEM (Melton et al., 2022); (2) develop future scientists (Orgill et al., 2019), engineers (Frank, 2012) and agriculturalists (Wang & Knobloch, 2023); (3) foster deeper consilience among STEM disciplines (Bryan et al., 2016; Moore et al., 2020; NGSS, 2013; NRC, 2014); and (4) connect learning to local communities (Kornegay, 2021) and cultural identities (Thies, 2023). Few researchers have studied how food systems thinking activities are designed (Charoenmuang, 2020), particularly when teachers face iSTEM pedagogical challenges (Herschbach, 2011; Wang et al., 2020).

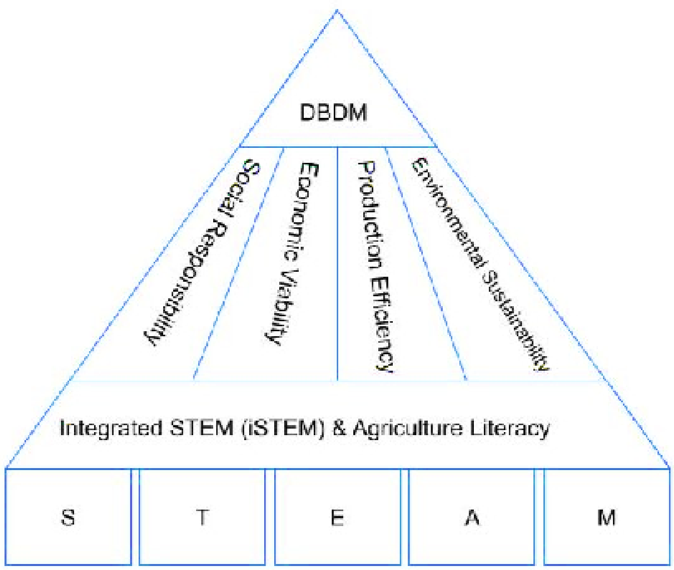
Students can learn to solve real-world complex problems within the content silos, but a PBL approach challenges students to solve a problem that spans across domains with a systems approach. PBL can be a tool for interdisciplinary teaching and integration (Weinberg & McMeeking, 2017) and engages students to collaborate with others to solve real-world problems as well as develop other 21st century skills (Bell, 2010). Further, PBL facilitated student autonomy because they chose the focus of their projects and designed and built the projects; the learner autonomy required students to set goals and have self-discipline. Bell (2010) identified responsibility, independence, and discipline as three outcomes of PBL. If PBL was implemented, it was important to know how the students perceived the iSTEM projects within the AFNR food system context, how they were motivated, and how they made connections to STEM and AFNR careers.

Theoretical/Conceptual Framework

Conceptually, the study was framed by three components: (1) integrated STEM and agricultural literacy, (2) agro-ecosystem thinking, and (3) data-based decision making. As shown in the conceptual framework model (Figure 1), the foundation of the food systems STEM project was built from the collaboration of the teachers from different content areas. Throughout the projects, high school students also developed their content knowledge from the individual disciplines of science, technology, engineering, agriculture, and mathematics (STEAM), and applied that knowledge through an integrated approach that blended the application, transferability, and knowledge of the individual silos. The integration of the STEM domains and agricultural literacy was best supported by co-developing and co-teaching the lessons with educators from different domains (Wang et al., 2020). The integration of the STEAM content silos helped students to develop their computational thinking skills. Through the AFNR context, students were challenged to focus their lens and take an agro-ecosystems thinking approach (Agunga et al., 2005) to complete the project. The systems thinking approach required students to analyze how problems were affected by environmental sustainability, production efficiency, economic viability, and social responsibility and to evaluate how their solutions would address agro-ecosystem factors (Charoenmuang, 2020; Fresco & Kroonenberg, 1992; McKim et al., 2017). The system factors that students addressed were further defined and studied through data collection. Students made data-based decisions and applied data literacy that required them to consider the four factors of systems thinking in addition to their integrated STEM and agricultural literacy understandings (Lai & Schildkamp, 2012). The top level of the framework, data-based decision making, drew upon the foundational STEAM discipline knowledge, the students' iSTEM and agricultural literacy knowledge, and the computational thinking skills of students and challenged them to critically analyze their projects.

Figure 1

Conceptual Framework



Note. DBDM = data-based decision making; STEAM = science, technology, engineering, agriculture, mathematics

Theoretically, self-determination theory (SDT) was used to frame the study of students' motivation. SDT explains how learners' psychological needs for competence, relatedness, and autonomy influence their motivation (Ryan & Deci, 2000). Students are motivated intrinsically and naturally seek to explore and learn based on their needs and sources of enjoyment. Intrinsic motivation is driven by enjoyment and interest of students, and the desire for competence and autonomy and is affected by a person's perceived competence. The project gave students autonomy because they chose the focus and design of their projects. Authentic motivation is influenced by the values that students hold and the learning environment's influence on the translation of those values. Students' perceived value and usefulness of the project reflects their task value motivation (Eccles & Wigfield, 2020). The food systems STEM project offered a unique context for students to translate their values. Because the projects were collaborative, students were able to interact with others and meaningfully work together towards a common goal. The different types of motivation that students have influences the effort that they expend on learning and project engagement (Kornegay, 2022; Thies, 2023).

Studies have applied self-determination theory to study student perceptions of integrated STEM projects of various domains, but often from the educators' perspectives or post-secondary students' perspectives (Akiri et al., 2020). Attitudes of students towards STEM in a project-based learning context has been studied but not within a food systems content (Tseng et al., 2011). The complementary approaches of systems thinking and iSTEM have not been studied outside of the science domains (York et al., 2019). Charoenmuang (2020) studied high school students food systems thinking, but did not use iSTEM as an approach. She found some students were able to demonstrate food systems thinking. Among those who demonstrated food systems thinking, they were motivated, open-minded, aware of holistic thinking, and had prior knowledge of various types of food systems. Students shared systems thinking was challenging and time-consuming, and they saw the benefits of systems thinking to help them understand and solve a complex problem. This study was unique because the educators participated in professional development to prepare them to implement the iSTEM projects that were contextualized within a food systems context and challenged students to apply systems thinking to solve a complex food systems challenge.

The purpose of the study was to describe high school students' motivations and perceptions of learning outcomes regarding the food systems STEM project. Three research questions guided this study: (1) What were high school students' motivations regarding the food systems STEM project? (2) What were high school students' perceptions of their learning experiences and outcomes during the food systems STEM project? (3) What were high school students' career interests in STEM and AFNR fields before and after participating in the food systems STEM project?

Methods

This descriptive study sought to describe high school students' motivations and perceptions of their learning experiences and outcomes after completing the Food System STEM Project (FSSP). Eleven teachers from nine high schools in Indiana taught 131 students who participated in the FSSP, and 93 students completed the questionnaire upon completion of the FSSP.

The 11 participating teachers completed professional development modules and participated in conversations with professionals and scientists to support the implementation of FSSP (Knobloch & Wang, 2024). Based on the social learning approach (Krasny, 2005), the teachers chose to co-teach with peers or co-develop content for the iSTEM through AFNR lessons. The teachers chose to present their students with a FSSP that addressed food sustainability, food waste, food deserts, and the advantages of hydroponic systems. The FSSP encompassed any problem from pre to post harvest including hydroponics, food science and safety, and sensors via agricultural robotics. The educators, from rural and urban schools, focused on different perspectives of the projects based on their curricula, classrooms and local contexts. Two of the urban schools focused on hydroponic systems; their students designed or redesigned and built different types of hydroponic systems. Agriculture and biology classes from a rural school focused on hydroponic and aquaponic projects. Students analyzed variables such as pH and the effect of fish on plant production efficiency. Another urban school presented students with a food sustainability challenge. Students were asked to use apples from an overproducing orchard to create a business model by baking different apple dishes and making sales decisions.

High school students engaged in inquiry and design-based PBL within the iSTEM through AFNR context by participating in a FSSP. A rubric was developed to outline the components of the projects and frame the showcase presentations (Nelson et al., 2022). Students identified a problem that could be solved by their project design. The criteria of a FSSP were to be innovative, feasible, viable, and desirable to the user or stakeholder. Connections to careers, their community, and personal connections were to be made by students by solving relevant problems. Throughout the FSSP, students applied systems thinking, specifically the four components of agro-ecosystems thinking: economic viability, social responsibility, environmental sustainability, and production efficiency (Agunga et al., 2005). Students collected data that were applied during their revisions and decision-making processes of the FSSP. Upon completion of the FSSP, students presented their design solutions to scientists and professionals. A rubric was used to review the FSSP to select awards to recognize different types of projects (e.g., Most Innovative).

A questionnaire was used to assess students' motivations and perceptions of their learning experiences and outcomes of the Food System STEM Project. The questionnaire consisted of four sections: (1) Overall Perception of the Food System STEM Project (12 items); (2) Perception of the Project Learning Experience and Outcomes (10 items); (3) Career Interest (12 items); (4) Demographics (4 items). Items were adapted from the Center for Self-Determination Theory's (2024) Interest Motivation Inventory to fit the context of the study. The scale consisted of: 1 = None / Not at all, 2 = A little, 3 = Somewhat, 4 = A lot, and 5 = Absolutely. Means were interpreted as "none / not at all" if they were between 0.00 to 1.49; "a little" if between 1.50 to 2.49; "somewhat" if between 2.5 to 3.49; "a lot" if between 3.50 to 4.49; "absolutely" if between 4.50 to 5.00. The questionnaire was adapted from the Interest Motivation Inventory (Deci & Ryan, 1982; Ryan & Deci, 2000), and was reviewed by a panel of experts for face and content validity. Under IRB approval, data were collected using an online survey tool (i.e., Qualtrics) after students completed the project. One hundred twenty-seven students responded to the questionnaire and resulted in 93 usable responses. The students that responded were from nine high schools in Indiana (i.e., five urban schools and four rural schools). Quantitative data were analyzed using descriptive statistics and decimals were rounded to the nearest hundredth value. Post-hoc Cronbach alpha coefficients were: 0.90 for interest and enjoyment (7 items), 0.94 for value and usefulness (7 items), 0.92 for perceived competence (5 items; one item was dropped after running the reliability analysis), and 0.77 for effort and importance (5 items). The reliability coefficient for perception of the learning experience and outcomes was 0.95 (10 items).

Students were asked an open-ended question, "What did you like about the Food System STEM Project?" Sixty-one students provided usable written responses. Qualitative data were coded using a descriptive coding method and similar codes were combined into categories. For example, learning about plants, animals and food topics as a category was the result of combining similar codes such as plants, aquaponics, fish, and fruit. Student quotes were cited for authenticity and trustworthiness (Shenton, 2004).

Results

Results are presented to answer each research question with supporting tables for the first and third research question. It is important to note the results are descriptive and should not be interpreted as causal outcomes.

RQ-1. Student Motivation. Results are presented for the first research question, "What were high school students' motivation regarding the food systems STEM project?" Upon completion of the FSSP, students reported they were motivated by the FSSP in response to the following SDT variables (i.e., interest, value and usefulness, competence, and importance) in the questionnaire. Students had "a lot" of interest in the project (*M* = 3.77, *SD* = .84). Among the participants who responded "a lot" and "absolutely," 62% enjoyed doing the food systems STEM project very much and 60% thought the project was very interesting. Students reported they found the project to have "a lot" of value and usefulness (*M* = 3.50, *SD* = .98). Among the participants who responded "a lot" and "absolutely," 60% agreed the food systems STEM project could be of some value to them and 59% thought it was an important project. Students reported they felt "a lot" of competence in completing the project (*M* = 3.58, *SD* = .89). Among the participants who responded "a lot" and "absolutely," 50% thought they were pretty good at doing the activities in the project and 45% agreed they were pretty skilled at the activities in the food systems STEM project. Regarding effort and importance, students reported they put forth "a lot" effort and saw "a lot" of importance in the project (*M* = 3.82, *SD* = .74; Table 1). Among the participants who responded, "a lot" and "absolutely," 64% agreed it was important for them to do well at the tasks and 60% agreed they put a lot of effort into the activities in the food systems STEM project.

Students were asked open-ended questions to learn what they liked and what they did not like about the food systems STEM project. Regarding what they liked, 80 students shared usable responses. Students liked the FSSP because of the following 14 reasons. First, they liked designing and building their project, which was supported with comments such as ""I loved the design and collaborative aspect", and "I liked being able to design my own experiment," and "building the prototype." Second, students like everything—the overall project was engaging, which was supported with comments such as ""I liked everything about it" and "it was very immersive; it had real world connections." Third, students liked learning integrated

Table 1

Student Reported Motivations of the Food System STEM Project

Items	None / Not at All	A Little	Somewhat	A Lot	Absolutely
Interest / Enjoyment					
I enjoyed doing the Food System STEM Project very much.	0%	10.1%	27.5%	37.7%	24.6%
This Food System STEM Project was fun to do.	0%	8.7%	27.5%	29%	34.8%
I thought the Food System STEM Project was boring. (R)	3.4%	3.4%	15.9%	39.1%	36.2%
This Food System Project did not hold my attention at all. (R)	8.8%	4.4%	27.9%	16.2%	42.6%
I would describe this Food System STEM Project as very interesting.	1.4%	11.6%	29%	30.4%	27.5%
I thought this Food System STEM Project was quite enjoyable.	3%	16.4%	19.4%	34.3%	26.9%
While I was doing this activity in this Food System STEM Project, I was thinking about how much I enjoyed it.	8.7%	15.9%	33.3%	23.2%	18.8%
Value / Usefulness					
I believe this Food System STEM Project could be of some value to me.	5.9%	11.8%	25%	32.4%	25%
I think that doing this Food System STEM Project is useful for helping me explore my college options.	11.8%	16.2%	30.9%	20.6%	20.6%
I think this is important to do because it can help me learn about college and career opportunities.	10.3%	16.2%	30.9%	19.1%	23.5%
I would be willing to do this again because it has some value to me.	4.3%	11.6%	21.7%	27.5%	34.8%
I think doing this Food System STEM Project could help me to consider college possibilities.	14.9%	17.9%	26.9%	20.9%	19.4%
I believe doing this Food System STEM Project could be beneficial to me.	2.9%	15.9%	31.9%	27.5%	21.7%
I think this is an important Food System STEM Project.	2.9%	8.8%	32.4%	30.9%	25%
Perceived Competence					
I think I am pretty good at the activities in this Food System STEM Project.	1.5%	14.7%	39.7%	23.5%	20.6%
I think I did pretty well at the activities, compared to other students.	4.3%	14.5%	33.3%	24.6%	23.2%
After working at these activities in this Food System STEM Project for a while, I felt pretty competent.	1.5%	16.2%	35.3%	20.6%	26.5%
I am satisfied with my performance in this Food System STEM Project.	2.9%	10.1%	26.1%	39.1%	21.7%
I was pretty skilled at the activities in the Food System STEM Project.	1.4%	15.9%	40.6%	27.5%	14.5%
These were activities I couldn't do very well. (R)	3.4%	17.4%	29%	20.3%	29%
Effort / Importance					
I put a lot of effort into the activities in the Food System STEM Project.	0%	7.2%	29%	30.4%	33.3%
I didn't try very hard to do well at the activities in the Food System STEM Project. (R)	2.9%	7.2%	18.8%	24.6%	46.4%
I tried very hard on the activities in the Food System STEM Project.	1.4%	8.7%	33.3%	30.4%	26.1%
It was important to me to do well at the tasks in the Food System STEM Project.	0%	10.1%	23.2%	39.1%	27.5%
I didn't put much energy into the activities in the Food System STEM Project. (R)	5.8%	8.7%	18.8%	29%	37.7%

Note. N = 69 Scale: 1 = None / Not at all, 2 = A little, 3 = Somewhat, 4 = A lot, and 5 = Absolutely. Reverse-scored items are denoted with an (R).

STEM through plant, animal and food sciences, which was supported with comments such as “the overall theme. It was well made,” and “[the FSSP] had a lot of hands-on work and it involved a lot of my personal interests around agriculture.” Fourth, students liked hands-on learning and developing skills, which was supported with comments such as “I liked that it was a hands-on experience and i enjoyed every minute of it” and “the amount of hands on work.” Fifth, students liked having fun and enjoyed the project, which was supported by comments such as “it was pretty fun and I [felt] like it [was] something that is important to learn about” and “the fact that it works and it was fun to build.” Sixth, students liked the project was interesting, which was supported with comments such as “it was new and exciting,” and “I liked how it taught me lots of things and how interesting it was.” Seventh, students liked learning about food, aquaponics, and plants, which was supported comments such as “making food and the label for it;” “I got to work with both plants and animals;” and “I liked how we learned how to grow plants using only fish waste.” Eighth, the FSSP was novel and something [content & context] students were not familiar with, which was supported with comments such as “it gave me a problem that I had to solve that I wasn't very familiar with,” and “it was different than any project I have ever done.” Ninth, students liked collaborating with their peers in solving real-world problems, which was supported with student comments such as “the overall theme. It was well made,” and “I liked how we could represent how food is processed in the world before it gets to us.” Tenth, students liked when their project design worked, which was supported with comments such as “I liked the freedom to use your own creativity to make a functioning real solution” and “I liked how our aquaponic system was fully functionable throughout our experiment.” Eleventh, students liked the overall theme of food systems, which was supported with a comment such as “it was pretty fun and I feel like it is something that is important to learn about.” Twelfth, students liked being creative, such as “brainstorming” and “being creative.” Thirteenth, students liked solving problems, which was supported with a comment such as “can be applied to the real world.” Finally, students liked developing leadership and relationships with community partners, which was supported with comments such as “I really enjoyed helping out at Jovial Farms” and “I am grateful [our teacher] set up the FFA program.”

Forty students shared usable comments regarding what they disliked about the FSSP. Students’ comments emerged in the following nine categories. First, students’ commented they disliked the FSSP because it was they were not interested and it was tedious and repetitive. Second, students shared there was not enough time to complete the project, they wanted to prepare more and the class went fast. Third, some students did not like the hands-on learning. They shared they didn’t like “working with water,” “cleaning out the fish tank,” or “making modifications to their aquaponics system.” Fourth, students shared they struggled to work effectively in teams (“I'm an introvert so in group projects I'm not allowed (by my group) to do much”) or did not like that some students did not perform their tasks, supported with a comment such as “some people didn’t make projects which was distracting.” Fifth, some students did not like the “writing the conclusions” and “the presentation project.” Sixth, some students shared they did not have the resources they needed to complete the project, such as “waiting on resources,” “did not have enough space,” and the “budget for the prototype was pretty limited.” Seventh, some students reported they thought the project was stressful and challenging. Eighth, some students did not like that the project was “not organized,” “confusing,” were given “limited communications.” Finally, one student shared they did not like their “how my plants weren't growing how I wanted.” It was interesting to note that some student comments were positive such as they didn’t like how fast class went, which implied they were engaged.

RQ-2. Learning Experience

The second research question was, “what were high school students’ perceptions of their learning experiences and outcomes during the food systems STEM project?” Overall, students perceived they “somewhat” completed the intended learning tasks and intended outcomes (*M = 3.45, SD = .93, Table 2*). A majority of the students agreed (a lot & absolutely) with five of the 10 intended learning outcomes: (1) 58% agreed they worked collaboratively with other students to apply the STEM concepts to solve the problem; (2) 57% agreed their design choices were based on evidence and justified with scientific reasoning; (3) 53% agreed the project helped them learn more about STEM careers; (4) 52% agreed they learned content from more than one STEM content area; and, (5) 50% agreed the project helped them analyze S/T/E/M concepts and design Furthermore, less than half the students agreed (a lot & absolutely) with five of 10 learning experiences and intended learning outcomes of the FSSP: (1) 45% agreed the project helped them develop multiple solutions in solving the real-world design challenge; (2) 43% reflected on how they applied STEM practices during the project; (3) 41% agreed they used digital technology (i.e., sensors) to collect data, which was used to create or modify the design solution; (4) 41% agreed the project helped them make connections to their everyday and personal experiences; and, (5) 40% agreed the real-world design challenge helped them make connections between STEM content and the food systems context.

RQ-3. Career Interests

The third research question was “what were high school students’ career interests in STEM and AFNR fields before and after participating in the food systems STEM project?” A paired sample t-test with Cohen’s d were performed to compare students’ interest in working in different careers fields retrospectively before and after the FSSP (Table 3). There was a significant difference with a small effect size ($p = .01$; $d = .30$) in student interest in working in science before (63% agreed; $M = 2.74$, $SD = .83$) and after (74% agreed; $M = 2.9$, $SD = .78$) the project. There was a significant difference with a small effect size ($p = < .01$; $d = .24$) in the interest in

Table 2

Student Reported Perception of the Food System Project Learning Experience

Items	None / Not at All	A Little	Somewhat	A Lot	Absolutely
The Food System STEM Project helped me make connections to my every day and personal experiences.	7.4%	17.6%	38.2%	17.6%	19.1%
The real-world design challenge helped me make connections between STEM content and the food systems context.	7.2%	13%	42%	20.3%	17.4%
The Food System STEM Project helped me develop multiple solutions in solving the real-world design challenge.	7.2%	13%	40.6%	14.9%	18.8%
The Food System STEM Project helped me to analyze S/T/E/M concepts and design solutions.	7.2%	11.6%	31.9%	27.5%	21.7%
I learned content from more than one STEM content area throughout the Food System STEM Project.	7.4%	10.3%	32.4%	29.4%	20.6%
I reflected on how I applied STEM practices during the Food System STEM Project.	7.2%	17.4%	29%	21.7%	24.6%
I worked collaboratively with other students to apply STEM concepts to solve the real-world design challenge.	5.8%	11.6%	24.6%	27.5%	30.4%
My design choices were based on evidence and justified them using scientific reasoning.	2.9%	13%	26.1%	30.4%	27.5%
I used digital technology / sensors to collect data, which was used to create or modify the design solution.	14.5%	17.4%	30.4%	23.2%	14.5%
The Food System STEM Project helped learn more about STEM careers.	11.8%	11.8%	25%	26.5%	25%

Note. N = 69 Scale: 1 = None / Not at all, 2 = A little, 3 = Somewhat, 4 = A lot, and 5 = Absolutely. Reverse-scored items are denoted with an (R).

Table 3

Student Reported Interest in STEM and AFNR Career Fields

Item	Before FSSP	After FSSP	*p*	*d*
I am interested in working in Science.	2.74 (.83)	2.90 (.78)	.01	.30
I am interested in working in Technology/Engineering.	2.60 (1.10)	2.89 (1.04)	<.01	.24
I am interested in working in Business.	2.49 (.93)	2.68 (.98)	.01	.20
I am interested in working in the Agricultural industry.	2.06 (.82)	2.42 (.91)	<.01	.42
I am interested in working in the Food industry.	2.19 (.80)	2.49 (.87)	<.01	.36
I am interested in working in the Natural Resources industry.	2.07 (.77)	2.34 (.89)	<.01	.32

Note. N = 69 Scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Agree, and 4 = Strongly Agree.

working in technology / engineering before (51% agreed; $M = 2.60$, $SD = 1.10$) and after (70% agreed; $M = 2.89$, $SD = 1.04$) the project. There was a significant difference ($p = .01$; $d = .20$) in the interest in working in business before (52% agreed; $M = 2.49$, $SD = .93$) and after (64% agreed; $M = 2.68$, $SD = .98$) the project. There was a significant difference with a small effect size ($p = < .01$; $d = .42$) in the interest in working in the agricultural industry before (25% agreed; $M = 2.06$, $SD = .82$) and after (48% agreed; $M = 2.42$, $SD = .91$) the project. There was a significant difference with a small effect size ($p = < .01$; $d = .36$) in the interest in working in the food industry before (34% agreed; $M = 2.19$, $SD = .80$) and after (52% agreed; $M = 2.49$, $SD = .87$) the project. There was a significant difference with a small effect size ($p = < .01$; $d = .32$) in the student interest in working in the natural resources industry before (26% agreed; $M = 2.07$, $SD = .77$) and after (44% agreed; $M = 2.34$, $SD = .89$) the project. Self-reported students' interests were significantly higher in all STEM and AFNR career fields, and all self-reported increases had small effect sizes. Students had self-reported higher increases for the AFNR career fields compared to science, technology/engineering, and business fields, yet they still had small effect sizes, which is interpreted that an expert in career development would be able to observe the increases.

Conclusions, Recommendations, Discussion/Implications

High school students perceived that a food systems STEM project generated interest in learning about STEM in the context of AFNR, engaged them to work collaboratively with other students to apply STEM concept and solve complex problems, generated design solutions using evidence and scientific reasoning, engaged them to learn more than one STEM area and analyze S/T/E/M concepts and design, and helped them learn more about STEM careers. Some students perceived the food systems STEM project offered a social environment for them to translate their values, fulfill their psychological desire for competence, and that it created a learning environment they felt was important and worth putting forth their effort in solving the complex design challenge. This conclusion aligned with Ryan and Deci's (2000) theory of self-determination motivation. Students shared comments that aligned with *autonomy* ("freedom"), *relatedness* ("collaborate"), and *competence* ("showed my skills") when asked what they liked about the food systems STEM project. Most students had limited experiences in AFNR, and they enjoyed learning about different aspects of food systems. It is important to note that students with limited prior experiences in AFNR found learning about the food system to be novel, interesting and engaging. Research is mixed regarding underserved and underrepresented students' perceptions of agriculture. For example, researchers found that minoritized youth had positive perceptions of agriculture (Jean-Philippe et al, 2017) and food science (Kornegay, 2021), yet Ortega (2011) found that minoritized youth were not interested in pursuing agricultural careers.

Students who are motivated to learn about agriculture, food and natural resources through experiential learning can develop interest and concern about the food system (Kornegay, 2021). Solving complex problems in the food systems can provide high school students career readiness skills (Charoenmuang, 2020; Nowell et al., 2020; FAO et al., 2020; Rosegrant & Cline, 2003). The results supported that federal support for transdisciplinary STEM education has been effective in addressing the goal of developing a "fuller appreciation of the intrinsic value of STEM" (National Science and Technology Council, 2018, p. 20). The food systems integrated STEM project was emotionally, behaviorally, and cognitively engaging for the students (Sinatra et al., 2015). Educators should use food systems integrated STEM projects to increase student motivation and support integrated STEM learning. Future research should compare the universal food systems context to other career and technical education clusters as contexts (e.g., manufacturing; human services). Elements of CTE contexts and authentic complex problems should be further studied to understand the universal design of how real-world complex problems can further develop career readiness outcomes (Hendrix, 2021). We recommend a deeper understanding of problem and project relevance be looked at across different domains in STEM and CTE. High school students agreed they based their project design decisions on evidence and justified them with scientific reasoning, aligning with The National Research Council's (2012) description that scientific reasoning is a complex process supported by data.

Results showed students agreed they worked collaboratively with other peers to apply STEM concepts, which supported Bell's (2010) finding that PBL promotes collaboration. Science and engineering are domains that depend on collaboration to produce new ideas, arguments, and evidence (National Research Council). The National Science and Technology Council identified STEM collaboration as a key piece to innovation and the future of America's economy. The food system STEM project helped develop authentic career skills including collaboration skills. Students agreed they learned content from more than one STEM domain and the project helped them analyze the S/T/E/M concepts and design. Students who learn through interdisciplinary approaches will learn skills that will be useful in interdisciplinary careers (Hernandez-Aguilera, et al., 2021). Students reported the learning experience helped them learn more about STEM careers. Food system STEM projects can be a tool to educate students about available STEM careers; future research should look at how food system project-based learning can address the high demand for STEM professionals (ACT Inc., 2017). Faculty in colleges of agriculture play an important role in recruiting high school students (Swan & DeLay, 2014) and should consider implementing K-12 outreach and engagement programs using a social learning approach, which helps K-12 teachers adapt and implement new curricula and project-based learning into their contexts (Kransy, 2003). Scientists and engineers in colleges of agriculture also play an important role in providing technical STEM and AFNR content knowledge to help high school teachers and students solve complex, authentic problems.

High school students reported higher interest in career fields such as science, technology / engineering, the agricultural industry, food industry, and natural resources industry after completing a food system STEM project. At the end of the project, a majority of students were most interested in science, technology / engineering, and business career fields. Agriculture and natural resources had the largest self-reported increase in students' career interests after completing the project and nearly half of the students were interested in AFNR career fields. Although this was not a causal finding, it did support Hand et al.'s (2023) conclusion that urban students of color are more interested in agriculture if they have positive learning experiences in agricultural education and precollege experiences (Cotton et al., 2009; Jean-Philippe et al., 2017; Kornegay, 2021). These findings aligned with previous research that has shown exposure to iSTEM education has a positive impact on career interests (Mohd et al., 2016). The results showed that the career pathways aligned with federal career and technical education policies support authentic iSTEM experiences for students have helped increase interest in STEM fields and have helped students make connections beyond the classroom (Hegerfeld-Baker, 2013). National Science and Technology Council, 2018). The authenticity of food system problems was noted by students as they shared that they liked the novelty and relevance of solving real-world problems that were interesting and engaging. Students also liked doing hands-on learning by designing and building a prototype of their design, and they felt competent when their design solution worked.

The study was limited due to the number of participants who completed the questionnaire. The results cannot be generalized beyond those who participated in the study. Future researchers should focus on increasing the number of participants to further analyze the construct validity of the questionnaire using factor analysis. Increasing the number of participants would also provide opportunities to study relationships using multiple regression analysis or structural equation modeling. Moreover, qualitative data should be collected using semi-structured or focus group interviews to more closely analyze the career interests of students after the food system STEM project. Food systems STEM projects allow students to use flexible inquiry and design-based project-based learning approach that teachers can apply in the classroom to engage their students and tailor to their local and classroom context. However, researchers have shown that PBL does not always generate increased results because there is less structure (Tirado-Morueta et al., 2021); this study should be replicated to further support the implementation of a food systems STEM project to generate student motivation. As such, food systems STEM projects should be studied based on different design criteria to determine different learning experiences and outcomes. Educators should implement food systems STEM projects to create interest in STEM career fields to help address the demand to fill the U.S. STEM and AFNR pipeline (Fernandez et al., 2020; National Academy of Sciences, 2009; NIFA USDA, 2024).

Summary

This study described high school students' motivations and perceptions of learning experiences and outcomes regarding the food systems STEM project. Results from this study showed that the food system STEM project provided an engaging learning experience that students self-reported allowed them to develop authentic career skills, apply evidence justified with scientific reasoning to support their decisions, take an integrated STEM approach, and learn more about STEM and AFNR careers (Hegerfeld-Baker, 2013). Food systems STEM projects should be implemented to increase student motivation and educate students about careers in STEM and AFNR fields (Craig & Alleman, 2016). Students self-reported the project was interesting and they liked the authenticity and relevance of the food systems context. Researchers should further explore how teachers adapt food systems STEM projects to engage their students and tailor learning to their local and classroom contexts. Because the results of this study are limited to the specific context and participants of the project, future researchers should further analyze the outcomes of the food systems STEM project as well as study the project model in different domains in STEM and CTE.

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