Journal of Agricultural Education, 65(4), 112-126
https://doi.org/10.5032/jae.v65i4.2766

The Impact of STEM Exposure on Students' Knowledge and Career Aspirations: A Biofuels Experience

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Abstract

Advocation for the STEM workforce in education has been noted from career sectors ranging from business to agriculture on local, state, and national levels. Modern agriculture is no longer only about manual labor and tending to crops and livestock, it has grown into a sophisticated field that heavily relies on STEM in virtually every aspect. Although research has explored school-based agricultural education (SBAE) students' interest in STEM and the perceptions of SBAE teachers related to STEM integration, little has been done to determine the impact of a STEM-enhanced curriculum on students' knowledge and their STEM interest. Undergirded with human capital theory, this study sought to determine the impact of a weeklong, immersive STEM curriculum experience on SBAE students' sustainable bioenergy content knowledge and STEM interest. The change in sustainable bioenergy examination scores resulted in a statistically significant difference with a large effect size. In addition, SBAE students reported an increase across the semantic scale for science, while other areas remained consistent or decreased. SBAE teachers should incorporate additional experiential learning activities by integrating STEM principles with a particular focus on mathematics, technology, and engineering to increase interest and career specific human capital.

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Introduction

The Vocational Education Act of 1963 (P.L. #88-210) shifted the focus of career and technical education to include *off-farm* occupations, adding the development of career-specific pathways and increased demand for integration of academics within school-based agricultural education (SBAE) (Camp & Crunkilton, 1985; Crawford & Cooper, 1986). These developments were further impacted according to the *A Nation at Risk* report, which presented evidence that Americans were educationally behind other nations' academics (National Commission on Excellence in Education [NCEE], 1983; United States Department of Education [USDE], 1984). Americans were depicted as illiterate in areas of science, influencing the need to increase educational rigor and requirements for public education (National Assessment for Education Progress [NAEP], 1982; USDE, 1984). Early educational reform targeted student-focused needs, resulting in academic growth in reading and basic mathematics; however, science and higher-order mathematics content requiring analysis were still found lacking (NAEP, 1982; USDE, 1984). The recommendations of the National Science Board (NSB) (1983) were to increase rigor and relevance of science and mathematics instruction and the integration of hands-on learning activities, which placed SBAE in an advantageous position for assisting in educational reform by preparing students for the 21st Century (National Research Council (NRC), 1988).

Advocation for the STEM workforce in education has been noted from career sectors ranging from business to agriculture on local, state, and national levels (Ferand et al., 2020; Roberts et al., 2020). Much of this is due to the continual shortfall of individuals with the necessary skills to enter STEM-related careers (National Academy of Engineering & National Research Council, 2014). Due to advancements in agriculture, and the interdisciplinary structure in which agricultural education can be embedded, school-based agricultural education (SBAE) serves as a vital preparation ground for STEM content (McKim et al., 2017). Although concepts such as science and mathematics are regularly integrated into SBAE, engineering and technology have historically been ill-represented within curricular resources (Eck et al., 2021; Wang & Knobloch, 2020). Agricultural education has continually been identified as an educational content area to which workforce skills and knowledge needs can be facilitated in the different STEM concepts and activities (Rothwell, 2013; Swafford, 2018a, 2018b). With SBAE having deep connections to applying curriculum to real-world applications (McKim et al., 2017), it is important to recognize the substantial benefits education and training in STEM integration can have within SBAE curriculum (Swafford, 2018). "This training becomes increasingly important considering the connection between K-12 student completion rates and their awareness of, curiosity about, and interest in STEM and STEM careers" (Eck et al., 2023a, p. 3).

In addition, modern agriculture is no longer just about manual labor and tending to crops and livestock. Instead, it has grown into a sophisticated field that heavily relies on STEM in virtually every aspect (National Institute of Food and Agriculture [NIFA], 2019). These aspects span from precision agriculture techniques like using drones to monitor crop health and automated milking systems to genetic engineering and data analysis for optimizing yields. Therefore, the future of agriculture demands a workforce well-versed in STEM fields, increasing the need for STEM integration in SBAE, with emphasis on curriculum that equips students with the knowledge and skills necessary to pursue careers in various agriculture-related fields (e.g., agricultural engineering, precision agriculture, food science, animal genetics, and sustainable fuels and energy). These careers are crucial for addressing global challenges like food security and sustainable agriculture (United States Department of Agriculture [USDA], 2023).

Although research has explored SBAE students' interest in STEM (Chumbley et al., 2015; Erickson et al., 2020) and the perceptions of SBAE teachers related to STEM integration (Smith et al., 2015; Stubbs & Myers, 2015, 2016), little has been done to determine the impact of a STEM-enhanced curriculum on students' STEM knowledge and interest. This becomes increasingly important as "the U.S. STEM workforce continues to be underprepared and lacking" (Watson et al., 2022, p. 2). Moreover, less than 16%

of high school students even considered a STEM-based career (Gonzalez & Kuenzi, 2012), yet the need persists for K-12 students to complete post-secondary, STEM-based degree programs (Seymour, 2002). Watson et al. (2022) identified a correlation between established and supported interest in STEM content and completion rates of K-12 students.

Purpose and Objectives

The study sought to determine the impact of a weeklong, immersive STEM curriculum experience on SBAE students' sustainable bioenergy content knowledge and STEM interest. Three research objectives guided this inquiry:

1. Establish the change in SBAE students' sustainable bioenergy content knowledge prior to and after a weeklong, immersive STEM curriculum experience;
2. Identify SBAE students' STEM and agriculture interest prior to and after being taught using a sustainable bioenergy curriculum; and
3. Identify SBAE students' career interest in STEM and agriculture prior to and after being taught using a sustainable bioenergy curriculum.

Theoretical/Conceptual Framework

The study was grounded in human capital theory. Human capital theory describes the process of developing a person's knowledge, skills, experiences, and proficiencies necessary for employability and overall wellbeing (Becker, 1964; Schultz, 1971; Smith, 2010). Human capital theory is acquired through education, training, and experiences (Bandura, 1984; Becker, 1964; Nafukho et al., 2004), which ultimately culminates in a more employable individual based on the development of "sector-specific" skills (Smith, 2010, p. 42). The acquisition of specific knowledge and skills not only benefits the individual who has an increased human capital, but also the organization and society for which they work and engage (Nafukho et al., 2004). Although human capital theory has been broadly implemented in economics and with teachers (Smylie, 1996), the career-specific human capital development of secondary students is limited.

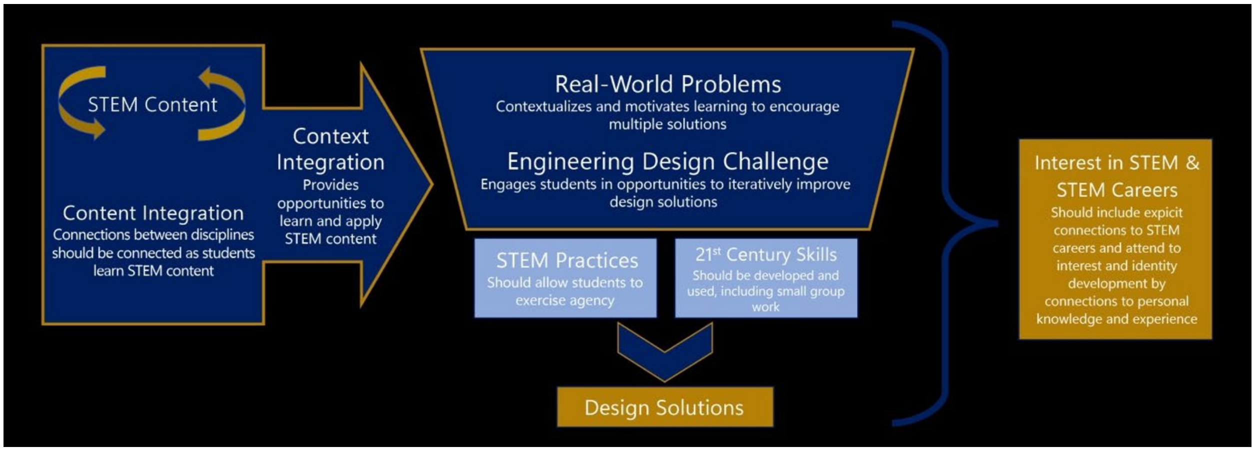
Within the scope of this study, STEM-focused agricultural careers across the bioenergy and renewable fuels sectors served as the specific human capital for which we were most interested in exploring and developing. To accomplish this goal, a STEM-enhanced curriculum on bioenergy and renewable fuels served as an educational experience for SBAE students. This study allowed for the exploration of equipping SBAE students' human capital in the realm of biofuels and renewable energy through a vetted STEM-enhanced secondary education curriculum that challenged students beyond rote memorization of facts and formulas, aiming to cultivate the critical 21st-Century skills, such as critical thinking, problem-solving, collaboration, communication, creativity, and innovation, that are highly sought by employers. These skills are essential not only for future careers in agriculture but also for success in any field or endeavor, regardless of career interests (NRC, 2012).

To further conceptualize the interaction of human capital development and STEM integration, Roehrig et al. (2021) established a detailed conceptual framework for integrated STEM learning in K-12 (see Figure 1). Roehrig et al. (2021) stated:

> Our framework builds upon the extant integrated STEM literature to describe seven central characteristics of integrated STEM: (a) centrality of engineering design, (b) driven by authentic problems, (c) context integration, (d) content integration, (e) STEM practices, (f) twenty-first century skills, and (g) informing students about STEM careers. (p. 1)

Figure 1

Conceptual Framework of Integrated STEM Education



Note. From "Beyond the basics: A detailed conceptual framework of integrated STEM," by Roehrig, G. H., Dare, E. A., Ellis, J. A., and Ring-Whalen, E, 2021, *Journal of Disciplinary and Interdisciplinary Science Education Research, 3*(11), p. 5 (https://doi.org/10.1186/s43031-021-00041-y).

The content within our study aims to clearly connect all STEM areas within agricultural education, providing an opportunity for students to solve real-world problems (i.e., sustainable energy, and engineering practices, i.e., bioplastics) in small group settings, aligning with the conceptual framework developed by Roehrig et al. (2021). Ultimately, the integrated STEM in SBAE project works to increase content knowledge in STEM and agriculture while establishing interest in STEM and agricultural careers.

Methods

This non-experimental, pre-test/post-test, one-group design (Privitera, 2020) was implemented to determine the impact a weeklong, immersive STEM experience had on SBAE students' knowledge about and interests in STEM. Students in three rural SBAE programs in Oklahoma during the spring 2023 semester ($N = 199$) were the accessible population for the study (Privitera, 2020). Each of the three schools were deemed rural according to the National Center for Education Statistics (NCES), with 8th through 12th grade school enrollment ranging from 65 to 234 students (NCES, 2023). Two of the SBAE programs were single-teacher programs. The other was a two-teacher program. All three served 8th through 12th grade students and represented two different areas of the state. The three participating programs had five classes per teacher per day, with each class lasting 50 minutes in duration. Individual class sizes ranged from six to 22 students.

The sustainable bioenergy curriculum was delivered by three graduate students pursuing doctoral degrees in Agricultural Education at Oklahoma State University. Each of the graduate students was a previous SBAE teacher with five or more years of teaching experience and participated in a two-hour, immersive STEM curriculum training program prior to their four-day teaching experience at one of the three assigned SBAE programs. The two-hour training program provided the graduate students with an intimate introduction to the curricular activities, materials, and resources, including the completion of all the immersive laboratory experiences. The STEM-enhanced curriculum was developed through a compilation of materials from National Ag in the Classroom (n.d.) curriculum, National 4-H Council (2016) activities, and from modules developed by the Department of Plant and Soil Sciences at Oklahoma State University to include four, 50-minute lessons. Learning goals were established and cross-walked with

National Agriculture, Food, and Natural Resources (AFNR) Standards (see Table 1), which are provided by the National Council for Agricultural Education (2015).

Table 1

Sustainable Bioenergy Curriculum and Corresponding AFNR Standards

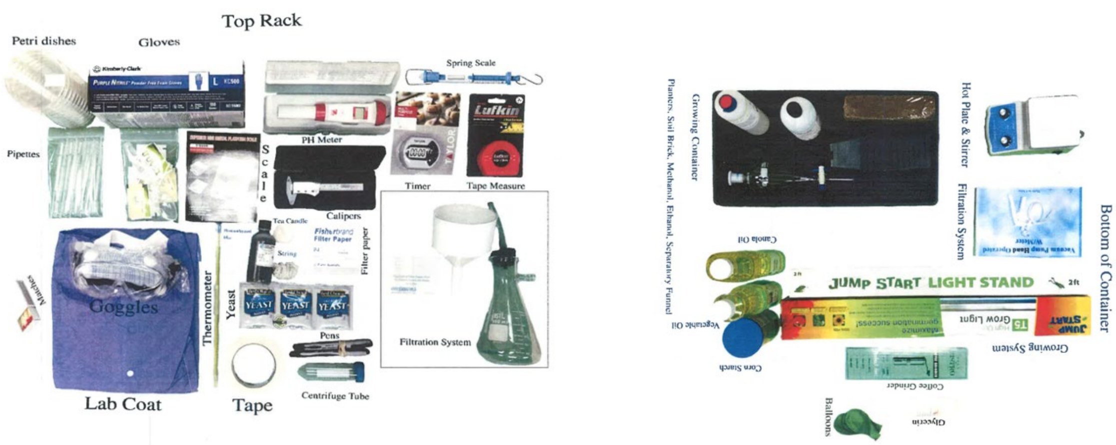
Learning Goals	AFNR Standards/Performance Indicators
Students will be able to define products derived from biomass.	NRS.03.01. Sustainably produce, harvest, process and use natural resource products (e.g., forest products, wildlife, minerals, fossil fuels, shale oil, alternative energy, recreation, aquatic species, etc.).
Students will be able to differentiate between biomass materials.	PS.01.03. Develop and implement a fertilization plan for specific plants or crops.
Students will be able to identify renewable options for making bioplastic.	PS.02.02. Apply knowledge of plant anatomy and the functions of plant structures to activities associated with plant systems.
Students will be able to test properties of multiple bioplastics.	PS.03.02. Develop and implement a management plan for plant production.
Students will be able to explain the growth and development of legumes.	ESS.01.02. Properly utilize scientific instruments in environmental monitoring situations (e.g., laboratory equipment, environmental monitoring instruments, etc.).
Students will be able to determine seeding rates.	BS.01.01. Investigate and explain the relationship between past, current and emerging applications of biotechnology in agriculture (e.g., major innovators, historical developments, potential applications of biotechnology, etc.).
Students will be able to calculate fertilizer rates.	BS.02.01. Read, document, evaluate and secure accurate laboratory records of experimental protocols, observations, and results.
Students will be able to extract oil from vegetable matter.	BS.02.02. Implement standard operating procedures for the proper maintenance, use and sterilization of equipment in a laboratory.
Students will be able to compare and contrast available oil from a variety of vegetable matter.	BS.02.03. Apply standard operating procedures for the safe handling of biological and chemical materials in a laboratory.

Students will be able to test the viscosity of oil.	BS.03.03. Apply biotechnology principles, techniques, and processes to protect the environment and maximize use of natural resources (e.g., biomass, bioprospecting, industrial biotechnology, etc.).

The learning goals aligned with daily topics within the curriculum including the history of biodiesel and bioenergy, bioplastics, plant growth, ethanol and fermentation, and oil extraction. Each day of the four-day experience, SBAE students were immersed in delivering critical content through relevant laboratory experiences. The laboratory experiences included biomass investigation, bioplastic production, soybean germination, seeding and fertilizing rate calculations, and the production of oil from vegetable matter. To support the graduate students' SBAE teaching experience, USDA NIFA sustainable bioenergy laboratory kits were prepared for each of the school sites, with a value of $1200 per kit (see Figure 2). Contents included a chemistry glassware set, hot plates, grow lights, calipers, spring scales, and pH meters, to name a few.

Figure 2

Sustainable Bioenergy Laboratory Kit



A 25-item criterion-referenced examination was used to measure sustainable bioenergy content knowledge. The examination was previously developed based on the sustainable bioenergy curriculum and used in previous research with SBAE students, which deemed the measure valid and reliable (Eck et al., 2023). In addition to the criterion-referenced questions, the modified and validated STEM semantics instrument (Knezek & Christensen, 2008) was included to assess students' perceptions of each of the five disciplines represented by agriculture and STEM and corresponding careers (i.e., a career in agriculture, and a career in STEM). The STEM sematic scale was deemed valid and reliable with high school students based on the findings of Christensen et al. (2014), with internal consistency reliabilities ranging from .89 to .93 across the five scales. Specifically, five questions were asked and ranked on a seven-point summated scale for each of the seven components. Figure 3 provides an example for science. The same format was followed for mathematics, engineering, technology, agriculture, a career in agriculture, and a career in STEM, with randomized ordering of the scales.

Figure 3

STEM Semantic Survey Example

STEM Semantic Survey: Choose one circle between each adjective pair to indicate how you feel about the subject.

To me, Science is:

1.	Fascinating	1	2	3	4	5	6	7	Mundane
2.	Appealing	1	2	3	4	5	6	7	Unappealing
3.	Exciting	1	2	3	4	5	6	7	Unexciting
4.	Means Nothing	1	2	3	4	5	6	7	Means a Lot
5.	Boring	1	2	3	4	5	6	7	Interesting

All data were collected in person using paper tests and sematic scale instruments. Pre- and post-tests were graded by the graduate students delivering the curriculum, and then one graduate assistant entered all pre- and post-test scores along with STEM semantic scores for each participant into SPSS Version 28. To address the first research objective, descriptive statistics were analyzed to establish a range in pre- and post-test scores along with group means. To statistically evaluate the change in knowledge from the criterion referenced exams, a paired samples *t*-test was used. In addition, Cohen's *d* was calculated for effect size (Field, 2018). The effect size output was evaluated and interpreted according to Cohen (1992) as being small (0.20), medium (0.50) and large (0.80). For the second and third research objectives, descriptive statistics were analyzed to determine the mode and percentage of agreement for each of the semantic scales.

The primary limitations within the study were related to instructional delivery. It was assumed all students in each SBAE classroom would be in class for all four days to complete the pre-test, four lessons, and the post-test. In addition to students physically being in the classroom, it was also assumed that students would be engaged in content delivery and immersive experiences. However, due to the timing of the sustainable bioenergy curriculum, which occurred in May of 2023, students were nearing the end of the school year (last week of school for one of the schools), which caused for frequent interruptions for varying school functions. Considering these factors, 47 pre-tests were removed from data analysis due to not completing the curriculum and post-test, leaving 152 complete data sets of students across the three programs who received all four days of instruction and completed the pre- and post-tests. There were an additional 35 STEM semantic instruments that were removed from data analysis due to incomplete data or straight-line responses.

In addition, although the graduate students received the same training, it is likely the actual delivery of the sustainable bioenergy curriculum, students, classroom resources (i.e., technology, room layout and orientation), and teaching styles may have varied from one school to the next. To ensure as much fidelity and consistency as possible, the accessible population was small due to the limitation of three Ph.D. students delivering the curriculum and the access to SBAE classrooms late in the spring semester. Therefore, the findings of the study should be considered in light of the limitations noted.

Findings

Research Objective 1: Establish the change in SBAE students' sustainable bioenergy content knowledge before and after a weeklong, immersive STEM curriculum experience.

One hundred and fifty-two SBAE students participated in a weeklong, immersive STEM curriculum experience focused on sustainable bioenergy. Prior to instruction beginning on day one, students completed a 25-question criterion-referenced examination to establish a content knowledge baseline. Each question on the examination was equally weighted and worth one point, for a maximum score of 25 points. Pre-test scores ranged from a low of four correct answers to a maximum of 18 correct answers, resulting in a mean score of 11.76 (*SD* = 2.89), which equated to a 47%, or an F letter grade. Four days of sustainable bioenergy curriculum followed the pre-test, culminating with a post-test to measure student growth at the end of the last day. The post-test used the same 25-questions as the pre-test but were reordered to offset test-retest effect. The same 152 SBAE students completed the post test, with scores ranging from a low of five to a perfect score of 25. The post-test resulted in a mean score of 15.65 (*SD* = 4.18), or a 62.6 (D letter grade).

To further understand the change in content knowledge based on the sustainable bioenergy curriculum, a paired samples *t*-test was analyzed, resulting in a statistically significant difference ($t = 12.23$, $p < .001$). Table 2 provides the pre- and post-test scores evaluated for the paired samples *t*-test.

Table 2

Student Score Comparisons from the Sustainable Bioenergy Curriculum

	n	*Mean*[a]	*SD*	*t*	*p*
Pre-Experience	152	11.76	2.89	12.23	.001
Post-Experience	152	15.65	4.18		

Note. [a]Mean scores were based on a 25-point criterion referenced sustainable bioenergy examination.

The change in sustainable bioenergy examination scores (mean difference = 3.89, *SD* = 3.93) resulted in a large effect size ($d = .99$) according to Cohen (1992).

Research Objective 2: Identify SBAE students' STEM and agriculture interest prior to and after being taught using a sustainable bioenergy curriculum.

To further understand the impact of the sustainable bioenergy curriculum, data were collected prior to and after the curriculum using a semantics scale focusing on agriculture and STEM (Knezek & Christensen, 2008). The semantic instrument had five randomized scales (i.e., 1 to 7) for each of the five content area items (i.e., science, mathematics, engineering, technology, and agriculture), but for consistency in data analysis, responses were recoded to align with one being negative (i.e., responses including *Mundane*, *Unappealing*, *Unexciting*, *Means Nothing*, and *Boring*) and seven being positive (i.e., *Fascinating*, *Appealing*, *Exciting*, *Mean a Lot*, and *Interesting*) on the sematic scale. Table 3 provides the mode and percent agreement for the five scale ranges across each of the five items. Overall, SBAE students reported an increase across the semantic scale for science, while mathematics, technology, agriculture, and engineering decreased.

Table 3

*SBAE Student Agriculture and STEM Semantic Ratings (*n *= 117)*

Item Stem	Semantic Scale	Before Mode	%[a]	After Mode	%[a]
Science is . . .	Mundane to Fascinating	4	23.1	5	21.4
	Unappealing to Appealing	3	19.7	4	25.6
	Unexciting to Exciting	4	23.9	5	27.4
	Means Nothing to Means a Lot	4	21.4	5	31.6
	Boring to Interesting	4	25.6	3	17.9
Mathematics is . . .	Boring to Interesting	7	27.4	6	24.8
	Unappealing to Appealing	6	24.8	7	23.1
	Mundane to Fascinating	6	21.4	6	22.2
	Unexciting to Exciting	4	29.1	4	34.2
	Means Nothing to Means a Lot	4	25.6	4	24.8
Engineering is . . .	Unappealing to Appealing	7	25.6	4	25.6
	Mundane to Fascinating	6	23.9	7	25.6
	Means Nothing to Means a Lot	7	27.4	7	24.8
	Unexciting to Exciting	6	17.9	4	25.6
	Boring to Interesting	6	21.4	5	23.1
Technology is . . .	Unappealing to Appealing	1	35.0	1	32.5
	Means Nothing to Means a Lot	1	37.6	1	25.6
	Boring to Interesting	1	29.1	1	24.8
	Unexciting to Exciting	1	35.0	1	29.1
	Mundane to Fascinating	7	22.2	4	20.5
Agriculture is . . .	Mundane to Fascinating	7	28.2	7	29.1
	Unappealing to Appealing	7	23.1	7	26.5
	Unexciting to Exciting	7	26.5	7	30.8
	Means Nothing to Means a Lot	7	27.4	7	26.5
	Boring to Interesting	7	44.4	7	41.9

Note. Scale of 1 to 7. [a]Percentage of correspondents selecting the mode.

Research Objective 3: Identify SBAE students' career interest in STEM prior to and after being taught using a sustainable bioenergy curriculum.

In addition to STEM and agriculture content interest, we sought to evaluate career interest in STEM and agriculture. To accomplish this goal a seven-point scale was used across five sematic scales for *A Career in STEM is* and *A Career in Agriculture is* (see Table 4). Although the mode remained consistent across the STEM career sematic scales, the percentage of students selecting the mode increased. The sematic scales for a career in agriculture remained consistent except for a change in mode from six to seven for *means nothing* to *means a lot* and a change from seven to four for the range of *unexciting to exciting*.

Table 4

*SBAE Student Agriculture and STEM Semantic Ratings (*n *= 117)*

Item Stem	Semantic Scale	Before Mode	%[a]	After Mode	%[a]
A Career in STEM is. . .	Boring to Interesting	4	20.5	4	27.4
	Unappealing to Appealing	4	19.7	4	28.2
	Mundane to Fascinating	4	24.8	4	33.3
	Unexciting to Exciting	4	26.5	4	35.9
	Means Nothing to Means a Lot	4	25.6	4	27.4
A Career in Agriculture is . . .	Unappealing to Appealing	7	24.8	7	24.8
	Mundane to Fascinating	7	26.5	7	25.6
	Means Nothing to Means a Lot	6	21.4	7	21.4
	Unexciting to Exciting	7	19.7	4	25.6
	Boring to Interesting	7	21.4	7	20.5

Note. Scale of 1 to 7. [a]Percentage of correspondents selecting the mode.

Conclusions/Discussion/Implications/Recommendations

The immersive STEM educational experience provided to students within the context of the sustainable biofuels unit resulted in a statistically significant increase in students' knowledge (t = 12.23, p < .001). Further, the mean difference of student scores from pre-test to post-test increased by 3.89, resulting in a large effect size (d = .99). Based on these findings, it can be concluded that students' comprehension of STEM based practices were enhanced through the weeklong instruction in sustainable biofuels. Student scores from pre-test to post-test increased 15.6% on average indicating the immersive educational experience provided was effective in increasing understanding of STEM principles. Although student scores increased, the average post-test score of 62.6% indicates student knowledge is still lacking regarding their performance on the criterion-referenced exam. Further instruction is needed for students to gain a better understanding of sustainable biofuels principles, and application of said principles could enhance further acquisition of STEM-related skills. Since SBAE enhances STEM training and potential workforce development (McKim et al., 2017), additional efforts should be made to expand STEM learning activities and applications within the sustainable biofuels curriculum. However, the situated learning experience was still successful in enhancing students' current knowledge regarding STEM practices and sustainable biofuels. Perhaps an increase in STEM-enhanced curriculum being delivered through SBAE programs following the framework presented by Roehrig et al. (2021) would further increase student knowledge gains and STEM practices (see Figure 1).

Moreover, student interest in science based on reported semantic scores increased across most items in the scale (4 of 5). Therefore, it can be further concluded that students' interest in science increased because of the instruction they received through the sustainable biofuels curriculum. Semantic scores for mathematics, technology, and agriculture neither increased nor decreased. Scores for semantic stems related to engineering decreased from pre-test to post-test. Engineering was the least represented STEM component within the biofuels curriculum delivered, and this lack of emphasis may have impacted student perceptions.

This conclusion supports the findings of Wang and Knobloch (2020) who found SBAE curriculum does not emphasize math, engineering, and technology as heavily as science. In addition, Nipyrakis et al. (2024) concluded that teachers identify science as a knowledge base, while engineering and technology are skill oriented. This becomes a greater concern as teachers struggle to identify what engineering is within K-12 education, including those teachers from an engineering background (Nipyrakis et al., 2024). Perhaps additional curricular support and exposure to STEM principles is needed for students to experience an increase in interest and enthusiasm for those areas. Teachers and curriculum developers should not feel pressured to incorporate each component of STEM into every individual lesson. The integration of STEM holistically across curricula serves as a value add for SBAE. This integration could be further enhanced using real-world problems and engineering design challenges as recommended by Roehrig et al. (2021). Student enthusiasm was highest for agriculture, as reported in both pre- and post-test semantic scores, which is not surprising since students were enrolled in a SBAE class at the time of data collection. This supports the findings of Eck et al. (2023) who identified an increase in student interest in agriculture and its related careers when students are taught situated STEM learning within agriculture. Perhaps grounding STEM based skills in additional agricultural context would lead to higher student enthusiasm for mathematics, technology, and engineering as well, which might increase the interest in STEM and STEM-related careers (Gonzalez & Kuenzi, 2012), which could positively impact the human capital and sector-specific skills (Smith, 2010) needed for employability in these industries (Bandura, 1984; Becker, 1964; Schultz, 1971; Smith, 2010).

Further, the increase in student achievement (i.e., knowledge and comprehension) based on the criterion-referenced pre- and post-test provides an indication of their acquisition of sector-specific skills (Haynes et al., 2012; Smith, 2010; Zimmerman, 1999), thus indicating enhancement of their human capital as it relates to STEM education. Since individuals prefer to acquire skills in areas that interest them (Smith, 2010), it can be inferred that as interest in STEM-related practices increases, so does their ability to build their sector-specific skills as they relate to STEM education. As such, students' reported scores related to the STEM semantic scale indicate their interest in and enthusiasm for agriculture and its related careers correlates to greater propensity to acquire skills in this area. Perhaps this increased interest in agriculture and agricultural careers is related to students being currently enrolled in an SBAE program, which lends itself to an increase in the interdisciplinary structure in which SBAE integrates STEM content (McKim et al., 2017; Swafford, 2018a).

Considering the goal of SBAE to be an educational content area to which workforce skills and content area growth can be facilitated in relation to STEM (Rothwell, 2013; Swafford, 2018a, 2018b), it becomes increasingly important that these STEM aspects span from precision agricultural techniques to drones and data analysis to meet the future workforce demands (USDA, 2023). Although the STEM-enhanced curriculum showed positive impacts regarding student content knowledge, a longer treatment experience is needed to impact students' long-term career interest in STEM and agriculture.

Recommendations for further research include expanding the scope of the study to include larger groups of students with additional analyses needed to compare factors impacting student learning such as program size, available educational resources, and community population. It is also recommended to include non-SBAE student populations to test the effectiveness of the curriculum and the impact of SBAE enrollment on STEM semantic scores. Longitudinal data collection would further help researchers and practitioners determine the impacts of STEM integration within SBAE and further validate the Conceptual Framework of Integrated STEM Education (Roehrig et al., 2021).

SBAE teachers should work to incorporate additional STEM principles with particular focus on mathematics, technology, and engineering to increase SBAE student interest in these areas and career-specific human capital. SBAE teacher preparation programs should work to further connect STEM concepts to agricultural curriculum and complete SBAE program delivery, helping to increase secondary students' STEM awareness and interest (Watson et al., 2022). Although efficient, perhaps developing ready-made curriculum with STEM-integrated lessons is not the most effective approach to increase STEM within

SBAE. Rather, SBAE teachers should be prepared in their preservice programs to integrate STEM within their curricula. In addition, establishing STEM-based communities of practice (COP) within secondary schools would support the integration of STEM in SBAE. For example, the COP could examine SBAE curricula and identify the naturally occurring STEM competencies in each lesson. These COP would allow the SBAE teacher to lean on the expertise of other STEM areas to help further students' understanding of and interest in STEM and STEM-based careers. In addition, SBAE teachers can serve as the expert to add agricultural context to other STEM content areas. SBAE teachers, teacher preparation faculty, and stakeholders should consider the future workforce needs within the various agricultural sectors (USDA, 2023) and the STEM emphases of those careers (NIFA, 2019) as they prepare and support SBAE teachers and students. STEM concepts within SBAE curricula should be aligned with the workforce needs of the local community. One approach should be accessing the SBAE program advisory committee for this process.

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