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Implications of Science Illumination on Student Content Knowledge of Technical Floriculture and Core Scientific Ideas

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Abstract

With fewer people entering agricultural career fields every year, the need for skilled workers in STEM fields continues to grow, which is an issue compounded by the growing demand for food and energy worldwide. An employment pool of skilled applicants who understand agriculture as a whole and comprehend applied concepts of STEM is needed, especially now as the world has stepped into an era of scientific and precision-based agriculture. School-based agricultural education (SBAE) provides opportunities to facilitate the application of core scientific ideas in real-world settings, as many agricultural contexts and problems typically involve numerous disciplines. This study analyzed the effects of purposeful science illumination on students' content knowledge of scientific core ideas and technical floriculture concepts. Students who received a specialized science illuminated curriculum displayed higher achievement on core science and technical floriculture content than their peers who received the standard curriculum. Further, students whose teachers received specialized training in STEM illumination outperformed the other two groups of students in both scientific core ideas and technical floriculture concepts. It is recommended that teachers seek both content-specific professional development opportunities and specialized curricula. Lastly, focus should be placed on methods of instruction to allow for students to engage with core scientific ideas within the context of agriculture.

Keywords: content knowledge; floriculture; horticulture; plant science; SBAE; science illumination; student achievement

Introduction and Literature Review

While farming has remained the integral focus of agriculture, 21st-century agriculture is now more broadly defined. The world has stepped into an era of "scientific agriculture," which encompasses almost the entire range of natural and social science (National Research Council, 2009). The "population monster" continues to increase food and energy demands, requiring more efficient agricultural production on less available space (Borlaug, 1973, p. 10; National Research Council, 2009). Unfortunately, as the need for skilled problem solvers in agriculture grows, public

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perceptions of agriculture as a less than desirable industry have led to fewer people directly engaged in agricultural activities than ever before (National Research Council, 2009). A specialized workforce is needed to address the complex problems within agriculture as the world steps into an era of "scientific agriculture" (National Research Council, 2009, p. 16).

The agricultural workforce requires an employment pool of skilled applicants who understand agriculture as a whole and who also comprehend applied concepts of science, engineering, technology, and math (STEM; National Research Council, 2009). Science, a core element of STEM, has been seen as a unique discipline that engages people in constructing knowledge and allows people to utilize that knowledge contextually (National Academies of Sciences, Engineering, and Medicine, 2016). Knowledge of science has become essential to be a productive member of society – to make impactful decisions about policy, and about personal medical decisions or consumer purchases (National Research Council, 2012). Science has also been key to solving some of the world's most significant issues, agricultural challenges included. Knowledge of STEM, and thus science, is a requirement for careers across all levels throughout many industries (National Research Council, 2011).

Industry and the education system must work in unison to prepare a workforce with high-STEM skills (CADRE, 2014). By the end of the 12th grade, students will need enough science knowledge to be functional members of society as informed consumers and decision-makers, regardless of future career paths. Additionally, students must continue to learn and utilize science throughout their lives (National Research Council, 2012). Unfortunately, student achievement has continued to be an area of concern if the United States remains a global player in the STEM workforce. The 1983 report, *A Nation At Risk*, was a call to action for student achievement in the United States (National Commission on Excellence in Education, 1983). Since then, legislation, such as *No Child Left Behind* (2001), has focused on monitoring students' achievement. However, the United States has remained "at-risk" in terms of student achievement. In 2015, 15-year-old students in the U.S. had lower science literacy scores than in 18 other educational systems globally, with even the highest-scoring U.S. students still below 14 other educational systems (Kastberg et al., 2016). The U.S. students who performed the lowest scored lower than students from 37 other education systems. These scores showed no measurable difference between science literacy scores in 2006, 2009, and 2012 (Kastberg et al., 2016). When looking at students in the 4th, 8th, and 12th grades, science literacy scores improved slightly from 2009 for 4th and 8th graders but remained the same for 12th-grade students. Only 34% of 8th graders and 22% of 12th graders were proficient or higher in science assessments (National Science Board, 2018).

When students can engage with core scientific ideas across multiple years of school, a deeper understanding of science will be developed (National Research Council, 2012). The opportunity to build on foundational concepts through meaningful learning experiences, such as real-world problems and situations, calls for an integrated approach to student learning. Career and Technical Education (CTE), specifically school-based agricultural education (SBAE), can provide a seamless education aligned with K-12 core scientific concepts by drawing on the active and applied learning strengths found in CTE. CTE has helped make scientific core ideas meaningful by providing opportunities to apply concepts through real-world contexts, such as agriculture (CADRE, 2014). SBAE provides ample opportunity to facilitate those opportunities, as many agricultural contexts and problems typically involve numerous disciplines (National Research Council, 2014).

The foundations of SBAE have resided in developing students' knowledge and skills in agriculture to support industry and occupational needs (Phipps et al., 2008). Comprised of three distinct structural components, SBAE is provided through classroom and laboratory instruction, supervised agricultural experiences (SAEs), and the National FFA Organization. Classroom and laboratory instruction have allowed students to understand and learn the principles and skills needed to solve complex agricultural problems (Phipps et al., 2008). SBAE curricula reflect real-world work experiences in agriculture, supported by scientific disciplines, and are rooted in the idea that students learn best through applying such knowledge (Phipps et al., 2008). Science illumination connects declarative knowledge and core ideas with teachers' procedural or technical knowledge (McKim et al., 2017). The illumination of science concepts in agriculture has allowed fundamental science concepts to be re-emphasized and applied concretely (Phipps et al., 2008). Teachers can be purposeful science illuminators, illuminator attempters where the teachers make an effort to illuminate science but cannot, or vocational purists where the teacher does not believe in incorporating science and SBAE (McKim et al., 2017). As an organized body, agriculture does not exist without biology, botany, genomics, physics, chemistry, entomology, and more (Kirby, 2002). While early SBAE was taught from the scientific standpoint, the Smith-Hughes Act of 1917 moved SBAE away from science and fully into education for vocation. However, the need for a broadly skilled and knowledgeable workforce has once again called for incorporating science and agriculture (National Research Council, 2009; Phipps et al., 2008).

The bulk of research related to students and STEM illumination in the SBAE curriculum has related to student behavioral factors, specifically student achievement (Despain et al., 2016; DiBenedetto et al., 2015; Haynes et al., 2012; McKim et al., 2018; Nolin & Parr, 2013; Pearson et al., 2013; Skelton et al., 2018; Smith & Rayfield, 2017; Thoron & Myers, 2011). Despain et al. (2016) and Nolin and Parr (2013) used state standardized tests to compare SBAE student achievement among science to non-SBAE students. Despain et al. (2016) conducted a longitudinal comparative analysis of high school SBAE students who earned science credit achievement versus the achievement of students who earned science credit through traditional core classes. Students in traditional biology courses scored higher than the students earning science credit for SBAE courses (Despain et al., 2016). Inversely, in Nolin and Parr's (2013) assessment of the relationship between the number of SBAE courses taken and achievement on the Alabama High School Graduation Exam (AHSGE), SBAE students' scores on the biology portion were comparable to the overall average for the exam of 72%. Further, the number of SBAE courses taken was a positive indicator of a student passing the biology section (Nolin & Parr, 2013).

Another thread of research in student achievement revolved around the impact of methods of teaching on student learning outcomes in science (DiBenedetto et al., 2015; Haynes et al., 2012; McKim et al., 2018; Pearson et al., 2013; Skelton et al., 2018; Smith & Rayfield, 2017). Pearson et al. (2013) discovered that a Science-in-CTE program in which a context-based approach was used to teach technical concepts that emphasized academic content was found to have a substantial, positive effect on post-test scores for students in the second, third, and fourth pre-test quartiles, with this magnitude increasing with each quartile increase. Smith and Rayfield (2017) indicated that the format in which STEM concepts are taught is vital to student understanding. Due to the abstract nature of many STEM concepts, the concrete application of content, such as that which is utilized in many SBAE courses, can improve student learning and student self-efficacy (Smith & Rayfield, 2017). Students who participated in science-enhanced animal science and horticulture courses were found to have higher mean scores on exams than students in traditional courses (Haynes et al., 2012).

SBAE enrollment and the impact on post-secondary education has also been investigated. In a nationwide study, McKim et al. (2018) found that student science achievement was a statistically significant predictor of 5% of the variance in post-secondary science grade point averages (GPAs). The number of SBAE classes taken was a significant, negative predictor of post-secondary GPA. The authors concluded that SBAE involvement was not linked to an increased

GPA or enrollment in science at the post-secondary level (McKim et al., 2018). In a reverse perspective, DiBenedetto et al. (2015) sought to understand the role of scientific reasoning in students' decisions to pursue future STEM or agriculture careers. Scientific reasoning scores were found to predict 17.3% – 54.3% of the likelihood to pursue a STEM career (DiBenedetto et al., 2015). The likelihood that a student would attend college was 87.3% to 95.8%, as predicted by scientific reasoning scores. The model of likelihood to pursue a career in agriculture was not statistically significant. Overall, DiBenedetto et al. (2015) observed that more than 92% of the students planned to attend college, with 40.2% planning to pursue a career in agriculture and 32.7% planning to pursue STEM careers.

Overall, much of the research related to STEM and SBAE has focused on student achievement outcomes (Despain et al., 2016; DiBenedetto et al., 2015; Haynes et al., 2012; McKim et al., 2018; Nolin & Parr, 2013; Pearson et al., 2013; Skelton et al., 2018; Smith & Rayfield, 2017; Thoron & Myers, 2011). Generally, a lack of meaningful evidence that STEM illuminated within SBAE increases students' scientific achievement has been observed (Despain et al., 2016; Haynes et al., 2012; McKim et al., 2017). However, overall science achievement has been noted as an influential factor (Despain et al., 2016; Haynes et al., 2012; McKim et al., 2017), as well as the method by which scientific concepts within agriculture courses are shown to impact student understanding (Haynes et al., 2012; Pearson et al., 2013; Smith & Rayfield, 2017). Additional research is needed to investigate the implications of science illumination within SBAE courses.

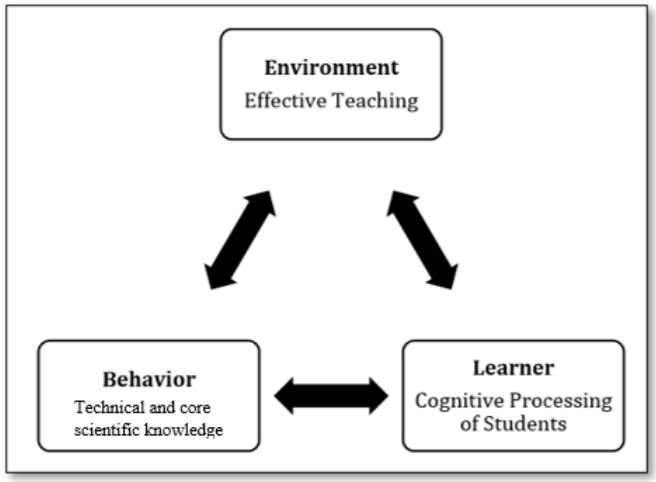
Theoretical Framework & Conceptual Model

Bandura's (1986) social cognitive theory guided this study. Based upon the model of triadic reciprocality, behavioral, personal, and environmental factors interact bidirectionally to influence actions (Bandura, 1989a, 1989b). While each factor functions independently of the others, each item influences the others. However, this influence can be represented by varying strength levels at any given point (Bandura, 1989a). Personal factors can be affected by one's beliefs, expectations, and cognitive ability. From the educational perspective, a teacher plays a vital role in shaping a student's environmental factors. Influences can include instructional strategies, teaching methods, feedback, and modeling. The level of impact of these items will vary due to a person's gender, experiences, age, and other factors (Bandura, 1986; Bandura, 1989a). People are both creators and outputs of their environment, which can be seen in the bidirectionality of personal and environmental factors (Bandura, 1989a).

Behavioral factors, or the performance of knowledge and skills, can be significantly shaped by a person's beliefs and actions. "People can effect change in themselves and their situations through their own effort" (Bandura, 1989b, p. 1175). Beliefs greatly influence this change in ones' capabilities. Reinforcement, such as feedback or the emphasis of a teacher's concepts, allows people to see what outcomes might come from a behavior. Thus, people are more likely to engage in behaviors they believe will result in positive outcomes (Bandura, 1986a). Behaviors impact environmental factors through routine transactions. The environment then provides insight into the behavior in which people participate (Bandura, 1989a). Additionally, personal factors such as thought patterns and previous experiences, such as foundational learning, influence a person's perceived capability and their participation in specific behaviors (Bandura, 1986a).

Estepp et al. (2013) presented an adapted version of the model of triadic reciprocality in which skills represent the behavior variable, the environment is teaching, and personal factors include the learner (Figure 1). This model was adapted further where the behavior component is represented by student achievement related to science illumination. The environment represents the teacher and the type of curriculum provided.

Figure 1
Adapted Model of Triadic Reciprocality (Estepp et al., 2013).



Purpose and Objectives

This study aimed to analyze the effects of purposeful science illumination on students' content knowledge of scientific core ideas and technical floriculture concepts. The objectives for this study were to:

1. Describe agriscience students' content knowledge of scientific core ideas;
2. Describe agriscience students' content knowledge of technical floriculture concepts and
3. Examine the effects of purposeful science illumination.

Methods

This study was part of a large-scale study (Ferand, 2021). According to the American Psychological Association (2020) Publication Manual, multiple publications from a large-scale research project can have the same methods section with some uniqueness. As such, how data were collected followed the same methodology (Ferand, 2021); however, this study focused on different variables. This quasi-experimental study utilized a multiple time-series, research design (Campbell & Stanley, 1963). This design was chosen due to its applicability to the school setting by using intact classrooms as groups and opportunities for repeated measures (Ary et al., 2010; Campbell & Stanley, 1963).

The study's population consisted of students enrolled in horticulture, floriculture, or plant science courses in grades 9-12 in the fall of 2020. A majority of students in this study were white (70.6%; n = 190) females (62.5%; n = 168), and in the 10th grade (23.8%; n = 87). Students ranged in age from 13–19 and were an average of 15.71 years old. Most students were in their second SBAE course (Min. = 1; Max = 8) and did not consider themselves members of the FFA (59.1%; n = 159). The majority of students in the study participated as part of their floral design course (47.2%; n = 127). The courses sometimes had other titles, including plant science, landscape design, and horticulture, among others. In eighty percent (n = 8) of the programs taught by the agriscience teachers, at least one SBAE course was offered for science credit, with 80% (n = 8) of the agriscience teachers certified to teach science in their state. Most of the students reported having taken biology (63.6%; n = 187) and/or chemistry (37.4%; n = 110) for core science credit with other courses including general science, earth/physical science, environmental science, marine science/biology, and physics. Upon graduating high school, most students planned to attend a two- or four-year college or university to earn a degree (73.6%; n = 198).

Students were recruited via convenience sampling methods. The sampling frame consisted of a convenience sample of secondary agriscience teachers who applied to the *STEM-it Up: Everything You Need to Know to Get Your Floriculture Curriculum in Bloom* (SIU) program. Students whose teachers participated in the SIU program were assigned to Group A. Students whose teachers chose to participate in the study were assigned either Group B or C, depending on their teachers' random assignment. Response rates per group across all three testing periods can be found in Table 1. Applications for the SIU program were distributed nationwide through listservs of national agricultural education organizations, such as the American Association for Agricultural Education, North American Colleges and Teachers of Agriculture, and the National Association of Agricultural Educators. Solicitations to apply for the program were also posted on social media groups for current agriscience teachers, such as the group "Ag Teacher Buddies" on Facebook.

Table 1

Number of Responses Per Group Across Testing Occasion

Group	Pre-Test	Post-Test	Post-Post Test
	n	*n*	*n*
A	165	137	110
B	52	53	47
C	15	14	14

To be eligible to apply for the SIU program, teachers with a minimum of two years' experience as of May 2020 were required to teach at least one high school level, or grades 9–12 horticulture, floriculture, or plant science course during the fall of the 2020-2021 school year. Teachers were assigned to one of three groups: A, B, and C. Group A teachers had participated in the SIU program, which took place during the summer and fall of 2020. The SIU program was "designed to deliver an intentional, systematic, and high-quality professional development with embedded inquiry-based opportunities focused on promoting exposure to horticulture/floriculture curricula" (Ferand et al., 2020, p. 191). SIU participant teachers received a three-day intensive professional development program in June, along with six 90-minute follow-up sessions that occurred each month from July through December 2020, resulting in a total of 40 contact hours of content-specific professional development. The conference and additional sessions included information on plant systems, the international flower industry, pathology, agriscience experiments, industry tours, and inquiry-based instruction. All teachers from the SIU program (N = 22) were invited to participate in the study. Five elected to participate. A two-week curriculum that emphasized the science behind the concepts related to the post-harvest care and conditioning of fresh-cut flowers was provided for Group A teachers to implement with their students.

Teachers who applied to participate in the SIU program, but who were not selected, made up Groups B and C. These teachers were invited to participate in the study and were randomly assigned to either Group B or C. Group B teachers received the same curriculum as Group A teachers (participants of PD program), which illuminated science concepts within a unit on post-harvest care of fresh-cut flowers. Group C teachers served as the constant and were only provided with the same curricular standards on post-harvest care of fresh-cut flowers, not the program curriculum. Group C teachers were fully responsible for developing all content and activities related to the standards.

The curriculum provided to teachers in groups A and B consisted of three lessons. All instructional materials were developed according to standards of inquiry-based instruction elements (Warner & Myers, 2008) and effective science instruction (Tweed, 2009). The lesson plans and curriculum unit's content validity was established through a panel of experts in agricultural education, inquiry-based instruction, and science education. The panel consisted of faculty and graduate students from two land grant universities. A full unit of instruction was provided that included a pacing guide, unit plan, lesson plans, and all materials and content to be taught. The unit focused on post-harvest care and conditioning of fresh-cut flowers. The unit was aligned with two Plant Systems standards and related sub-standards from the AFNR Career Cluster Content Standards (National Council for Agricultural Education, 2015; see Table 2). These standards were then aligned with the Next Generation Science Standards as provided in the AFNR Career Cluster Content Standards and according to the related content (National Council for Agricultural Education, 2015; National Research Council, 2012; see Table 2).

Table 2

AFNR and NGSS Standard Alignment

AFNR Plant Systems Standard	NGSS Standard
PS.02. Apply principles of classification, plant anatomy, and plant physiology to plant production and management. PS.02.02. Apply knowledge of plant anatomy and the functions of plant structures to activities associated with plant systems.	HS-LS1-2 – Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.
PS.02.03. Apply knowledge of plant physiology and energy conversion to plant systems.	HS-LS1-5 – Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.
PS.03. Propagate, culture and harvest plants and plant products based on current industry standards. PS.03.05. Harvest, handle, and store crops according to current industry standards.	HS-LS1-2 – Develop and use a model to illustrate the hierarchical organization of

The three lesson plans were developed to accommodate 45-minute classes, for a total of two weeks of instruction. Teachers who taught on a block schedule of 90-minute classes were instructed to teach two days of instruction in one class period, which resulted in the same amount of instructional time. Each of the three lessons focused on different aspects of post-harvest care and conditioning of fresh-cut flowers. Topics were grouped by standard and relationship to post-harvest care. Lesson One focused on transpiration and translocation within plants. Lesson Two highlighted photosynthesis and reviewed other systems within plants. Lesson Three reviewed industry techniques for flower quality and conditioning related to the previously learned information on plant systems. The timing varied by lesson. A pacing guide and suggestions for the duration of each activity were provided. However, teachers were given permission to adjust these suggestions based on their students' progress, situation, and unforeseen events.

Due to unforeseen circumstances, and the fluid nature of instruction during the COVID-19 pandemic, an extra three weeks was provided as a grace period for teachers to complete all of the instruction and the post-test during the scheduled time frame. Throughout the study, teachers were contacted weekly by email or telephone with reminders and to provide any needed assistance. Additionally, teachers' instructional methods, such as face-to-face, online live, online asynchronous, or mixed online and face-to-face, varied from school to school and daily. Based on the original activity format, modification options for laboratory and summary activities were provided throughout each lesson. Teachers were instructed to choose the most appropriate option for their students, resources, and overall situation. The options and modifications did not alter the intended content in any way.

Instrumentation

To determine student content knowledge, we developed a criterion-referenced assessment was developed to measure students' achievement related to core scientific ideas and technical floriculture concepts. The instrument measured both sections' content knowledge for the entire curriculum unit and consisted of 38 total questions. Questions were aligned with AFNR Career Cluster Content Standards and Next Generation Science Standards. The instrument had a maximum score of 38 points, with the raw score being based on the number of questions each student answered correctly. Questions were separated into two main sections of science and floriculture. The science section consisted of 24 questions related to plant parts, photosynthesis and respiration, and translocations and transpiration. The floriculture section consisted of items focusing on production, conditioning, and processes and was 14 questions in total. The assessment was provided in a multiple-choice format.

Students completed the assessment on all three testing occasions (pre, post, and post-post) via Google Forms. The pretest was given in the week immediately preceding the implementation of the curriculum intervention. The posttest was provided in the week immediately following the completion of the curriculum. Finally, the post-post test was administered during the first week of December 2020, approximately two months after completion of the curriculum interventions. Teachers were provided with unique links for their students, and the assessments were password-protected to prevent academic dishonesty. Students did not receive feedback on their performance between the pre and post-test nor between the post-test and post-post test. Teachers did have the option to use students' results on the post-test as a grade in their classes. If teachers chose this option, we sent coded student scores to their teacher.

Face and content validity were established through a panel of experts consisting of agricultural and science education faculty at two land grant universities. This panel was considered experts based on their experience in teaching and learning, science integration, and experience with secondary teaching, curriculum, and instruction. Wiersma and Jurs (1990) indicated that criterion-referenced tests, such as those used in this study, do not require reliability estimates, but instead provide criteria for establishing reliability. The criteria and the actions taken to establish reliability are presented in Table 3.

Table 3

Actions Taken to Establish Reliability for Student Assessment

Criteria	Action
Homogenous Items	All items were in a multiple-choice format. Each item was linked to a unit objective and aligned with provided standards.
Discriminating Items	The authors and a panel of agricultural and science education faculty at two land grant universities reviewed the items and confirmed a range of difficulty.
Enough Items	The assessment consisted of 38 items covering two sections and six sub-sections.
High Quality Format	The assessment was presented via Google Forms for uniformity. Questions were grouped by section and sub-section. A panel of agricultural and science education faculty at two land grant universities reviewed the items for face and content validity.
Clear Direction for the Students	Students were provided with both written and verbal directions for the assessments. A panel of agricultural and science education faculty at two land grant universities reviewed the directions.
A Controlled Setting	Teachers in each group were provided with unique links for each assessment. Each assessment was password protected and the classroom teacher administered them.
Motivating Introduction	All students provided assent to participate in the study and parents' consent. Both the assent and consent forms contained information that explained the study and the impact of the results on future students.
Clear Directions for the Scorer	The assessment was automatically scored via the key provided by the researcher in Google Forms. All scores were further verified when reviewed in Excel and entered into SPSS for data analysis.

Data Analysis

Data were analyzed using SPSS Version 26. Descriptive statistics in the form of means, and standard deviations were used to measure all objectives. Frequencies, mean, and standard deviations were used to measure demographic data. Summated scores were calculated for each student to find a grand mean for each group across all three periods to address Objective Three and to provide the grand means to address parts of Objectives One and Two.

Limitations

This study's population consisted of students of agriscience teachers who applied to be part of the SIU program. The sample was a convenience sample from this population. Therefore, the findings of this study were not generalizable beyond the population of students whose teacher applied. While the SIU application was distributed nationwide, the application pool could not be assumed to represent the current teaching force of floriculture agriscience teachers in the U.S.

Additionally, the COVID-19 pandemic greatly impacted this study's timeline and overall participation. Two teachers, one each from Groups B and C, opted not to participate due to strain from online and high-flex teaching and constantly evolving class schedules and thus their students did not complete the instrument. Further, several teachers across all three groups faced school delays, which postponed their students' post and post-post tests. Lastly, the strain of being a student during the COVID-19 pandemic should be considered. Many students intermittently attended school due to unplanned closures and were forced to learn online asynchronously while at home alone. The impact of the pandemic on student achievement, success, and motivation, should be included in the conversation on results from this period of time. We acknowledge all the limitations of this study and lament the time period in which the data was collected.

Results

Objective One was to describe agriscience students' content knowledge of scientific core ideas. Mean and standard deviations by group for all three testing occasions are presented in Table 4.

Table 4

Agriscience Students' Content Knowledge of Scientific Core Ideas

Section	Group	Pre-Test		Post-Test		Post-Post Test	
		M	*SD*	*M*	*SD*	*M*	*SD*
Plant Parts[a]	A	2.48	1.44	3.85	1.55	3.55	1.66
	B	2.85	1.36	3.55	1.64	3.06	1.48
	C	2.27	1.49	3.50	1.45	2.43	1.55
Photosynthesis and Respiration[b]	A	5.59	2.66	7.07	2.88	5.93	2.70
	B	6.17	2.60	6.45	2.55	6.32	2.37
	C	5.40	3.07	6.79	2.94	5.29	2.73
Transpiration and Translocation[c]	A	1.86	1.18	2.42	1.50	2.21	1.36
	B	1.85	1.21	2.47	1.23	2.64	1.89
	C	1.60	1.12	1.57	0.85	2.29	1.68
Grand Mean[d]	A	9.93	4.07	13.34	4.67	11.68	4.78
	B	10.87	3.92	12.47	4.63	12.02	4.79
	C	9.27	4.57	11.86	4.35	10.00	5.19

Note.[a] Sub-section = 6 items. [b]Sub-section = 12 items. [c] Sub-section = 6 items. [d]Section = 24 items.

All three groups displayed an increase in the plant parts sub-section, with Group A having the largest growth (pre-test M = 2.48 (1.44); post-test M = 3.85 (1.55); post-post test M = 3.55 (1.66)).

Groups A and B showed at least slight increases in the photosynthesis and respiration sub-section. Group C had a slight decrease from the pre to post-post test, with an increase in score for the post-test period (pre-test *M* = 5.40 (3.07); post-test *M* = 6.79 (2.94); post-post test *M* = 5.29 (2.73)). As with plant parts, all three groups showed an increase in scores for the transpiration and translocation sub-section, with Group B having the highest post-post test scores, as well as the greatest increase from pre to post-post testing (pre-test *M* = 1.85 (1.21); post-test *M* = 2.47 (1.23); post-post test *M* = 2.64 (1.89)). Group A indicated the most growth in the science section with a positive overall gain of 1.75 points (pre-test *M* = 9.93 (4.07); post-test *M* = 13.34 (4.67); post-post test *M* = 11.68 (4.78)). Similarly, both Groups B and C also demonstrated positive growth overall.

Objective Two focused on describing agriscience students' content knowledge of technical floriculture concepts, with means and standard deviations for this section presented in Table 5.

Table 5

Agriscience Students' Content Knowledge of Technical Floriculture Concepts

Section	Group	Pre-Test		Post-Test		Post-Post Test	
		M	*SD*	*M*	*SD*	*M*	*SD*
Production[a]	A	3.12	1.29	3.92	1.19	3.48	1.11
	B	3.37	1.19	3.43	1.37	3.87	1.03
	C	2.93	1.49	3.29	1.49	2.93	1.27
Conditioning[b]	A	1.31	1.09	2.26	1.09	2.21	1.23
	B	1.27	0.93	1.74	1.26	2.00	1.12
	C	1.27	0.96	2.21	1.37	2.07	1.27
Processes[c]	A	1.08	0.97	1.92	1.21	1.60	1.01
	B	1.04	0.99	1.53	0.91	1.77	1.05
	C	1.40	0.91	1.50	1.09	1.07	0.83
Grand Mean[d]	A	5.52	2.04	8.09	2.38	7.29	2.48
	B	5.67	1.99	6.70	2.17	7.64	2.39
	C	5.60	1.92	7.00	3.11	6.07	2.43

Note. [a]Section = 6 items. [b]Section = 4 items. [c]Section = 4 items. [d]Section = 14 items.

For the production sub-section, Groups A & B exhibited positive growth across the three testing periods. Inversely, Group C showed positive growth from the pre to post-testing periods but ended the post-post period with no change from the pre-test (pre-test *M* = 2.93 (1.49); post-test *M* = 3.29 (1.49); post-post test *M* = 2.93 (1.27)). Additionally, all three groups indicated growth for the conditioning sub-section, with Group A having the largest increase between the pre and post-post periods (pre-test *M* = 1.31 (1.09); post-test *M* = 2.26 (1.09); post-post test *M* = 2.21 (1.23)). In the processes sub-section, Group A and B showed growth, but Group C demonstrated a decrease in score from the pre to post-post testing periods (pre-test *M* = 1.40 (0.91); post-test *M* = 1.50 (1.09); post-post test *M* = 1.07 (0.83)). For the floriculture section, Group A displayed the largest amount of growth, with a 1.97 increase in the score from the pre to post-post testing period (pre-test *M* = 5.52 (2.04); post-test *M* = 8.09 (2.39); post-post test *M* = 7.29 (2.48)). All three groups experienced growth in this section.

The third and final objective of this study was to examine the effects of purposeful science illumination. Mean and standard deviations of the overall summated score per group across the testing periods are displayed in Table 6.

Table 6

Agriscience Students' Summated Assessment Scores

Group	Pre-Test		Post-Test		Post-Post Test	
	M	*SD*	*M*	*SD*	*M*	*SD*
A	15.44	5.00	21.51	6.37	19.10	6.31
B	16.54	5.04	19.17	6.07	19.66	6.77
C	14.87	6.07	19.21	5.67	16.07	6.37

Note. Maximum score = 38 points

All three groups showed growth in summated scores throughout the study. Group A indicated the largest amount of growth overall with a positive increase of 3.66 points between the pre and post-post tests (pre-test $M = 15.44$ (5.00); post-test $M = 21.51$ (6.37); post-post test $M = 19.10$ (6.31)). Group B exhibited a 3.12-point growth (pre-test $M = 16.54$ (5.04); post-test $M = 19.17$ (6.07); post-post test $M = 19.66$ (6.77)), while Group C indicated 1.20 points growth (pre-test $M = 14.87$ (6.07); post-test $M = 19.21$ (5.67); post-post test $M = 16.07$ (6.37)).

Conclusions & Discussion

This study's population included students whose teachers applied to be part of the SIU professional development program. The sample was convenient in nature, and the findings of this study are therefore not generalizable beyond the population of students who participated. The COVID-19 pandemic significantly impacted the overall participation of the teachers and the scheduled timeline of this study. Three teachers, one each from Group A, B, and C, discontinued their participation due to stress from the pandemic and hectic teaching schedules. Further, several classes across all three groups experienced school delays due to the pandemic, postponing their post and post-post tests. Lastly, response rates across the testing occasions decreased dramatically despite best practices. We acknowledge these factors as major limitations to the study.

Overall, all three groups displayed increased achievement in their summated assessment scores. Students in Group A, in which teachers received the specialized professional development and utilized the illuminated curriculum, showed the greatest improvement in scores from the pre to post-post testing period. These results indicated that the teachers who received the content-specific professional development materials, along with the specialized curriculum, experienced results that were beneficial to the students' behavioral outcomes, and their achievement supported the use of social cognitive theory (Bandura, 1986, 1989b). Our results aligned with previous findings indicating that curricula with enhanced aspects of core scientific ideas improved student achievement (Haynes et al., 2012; Pearson et al., 2013).

Interestingly, Groups A and C had higher post-test scores than post-post test scores, while Group B showed a further slight increase in achievement from the post to post-post tests. The trend of post-test scores being higher than post-post test achievement was seen for all three groups for the floriculture section, and Groups A and C in the science section. As mentioned as a limitation of this study, the post-post testing was delayed in several cases because the schools were closed due to the pandemic. Post-post tests were taken at the end of the semester, just before many students took their break for the winter holiday. Further, while the overall results are positive, all three groups' final assessment scores would still be considered failing, raising concern for long term application of the content. Overall improvement was seen across all groups from the pre to post-

post tests, but the impact of other environmental factors, such as the pandemic and the impending holiday should be considered when interpreting the results.

Group A realized the largest increase in student attainment for the science section, with the largest increase for this group appearing in the plant parts subsection. Groups B and C displayed the greatest improvement from pre to post-post test scores in the transpiration and translocation subsection. Improvement in the science section of the assessment is encouraging as science achievement has been noted as impactful on post-secondary enrollment (McKim et al., 2018). Further, scientific reasoning has been linked to an increased likelihood of pursuing a STEM career (DiBenedetto et al., 2015). These findings, linked with previous literature, are encouraging results that demonstrate that SBAE courses with science illumination can support understanding and knowledge of core scientific ideas, in addition to increasing the likelihood of filling the need for a skilled agricultural workforce (National Research Council, 2009).

Again, Group A revealed the most improvement of nearly a two-point difference from pre to post-post test scores in the assessment's floriculture section. Groups B and C also showed improvement, but both had less than 0.5 points from pre to post-post test scores. The conditioning sub-section was the area where all three groups showed the most improvement throughout the study. These results support the skilled workforce called for by the National Research Council (2009), especially in conjunction with the improvement seen in the assessment's science section. However, it remains to be seen if the increase in student achievement does or can impact students' views of agriculture as an industry or their desire to pursue such careers (National Research Council, 2009). Despite positive results from all the groups and recommended guidelines provided by Wiersman and Jurs (1990), the assessment's floriculture section should be evaluated for future study iterations. All three sub-sections (processes, production, and conditioning) had at least two questions commonly responded to incorrectly by students across all three groups.

In conclusion, Group A students, whose teachers received a content-specific professional development and experienced a specialized curriculum, showed higher assessment scores in both the science and floriculture sections. Additionally, Group B students who just received the curriculum illuminated science concepts within the floriculture unit also showed greater improvement than those in Group C who experienced their teachers' typical instruction. Together, these results indicated that the environmental factors of a student's SBAE classroom, such as their teachers' previous knowledge and the curriculum presented, positively impacted the student behavioral outcomes of both floriculture and science achievement in the floriculture curriculum.

Recommendations

Recommendations for further research focus first on replicating this study with a larger sample size. As mentioned as a limitation, this study's results cannot be generalized beyond the population utilized. Additionally, the COVID-19 pandemic contributed to multiple issues throughout the study. Therefore, we recommend additional replications of this study to further solidify results. Additional recommendations for research are inclusion of student demographics and perceptions to determine the influence of environmental factors on students' achievement. Student motivation to learn science or interest in careers in the agriculture industry should be considered to help recruit the called for adequate workforce (National Research Council, 2009). Additional personal factors that might influence student achievement include student demographic data and whether or not SBAE courses are offered for science credit. Lastly, the impact of additional environmental factors, such as the teachers' perceptions toward integrating science or their openness to science illumination, should be considered for future studies.

We recommend that current classroom teachers seek out both content-specific professional development opportunities and specialized curriculum. Specifically, for science illumination, the teachers' knowledge of scientific core ideas and technical agriculture are needed to be effective illuminators (McKim et al., 2017). The environment that teachers create for their students through the teachers' preparation should not be discounted. The teacher is an essential factor in a student's cognitive development. Suppose a teacher does not fully understand the content they teach? In that case, they are less likely to spend as much time on that content (Ramey-Gassert & Shroyer, 1992) and they will not afford their students a holistic understanding of the topic. We encourage teachers to initiate change within themselves if they desire to see a change within their classroom environment and their students' cognitive gains.

Pre-service SBAE teachers should be provided with both core science courses, as well as courses on how to integrate science into their future programs. Providing teachers with experiences and knowledge in science integration prior to entry into the profession can help remove barriers and provide an expectation of integration before they even enter their classrooms. Curriculum that illuminates science within SBAE courses should be distributed to both preservice and in-service teachers. Providing content focused resources helps remove barriers of preparation, especially when lack of knowledge on where to integrate science into specific pieces of their courses exists. Finally, students should be allowed to engage with core scientific ideas that are embedded into their SBAE courses. Students can apply abstract ideas into concrete experiences through the structure of SBAE related to the three-circle model. Only through high-quality teacher PD and enhanced content-focused curricula will students have the opportunity to engage with, make connections to, and apply the core science subject matter learned in their SBAE classes.

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