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Multiple Case Study of STEM in School-based Agricultural Education

Eric A. Stubbs[1] and Brian E. Myers[2]

Abstract

This multiple case study investigated the integration of science, technology, engineering, and mathematics (STEM) in three Florida high school agriculture programs. Observations, interviews, documents, and artifacts provided qualitative data that indicated the types of STEM knowledge taught. Variables of interest included student and teacher perceptions, teacher education, demographics, STEM integration, STEM knowledge, and student achievement and engagement. Each program taught students about a variety of STEM disciplines and careers. This study has added to the body of literature indicating student achievement in STEM can be increased by agricultural education. Science and technology were reliably integrated at high levels, but engineering and mathematics concepts were less consistently integrated across cases. Five case study propositions regarding the integration of STEM and the other variables of interest were accepted. Areas for further research within AG-STEM teacher education, teaching methods, and curriculum resources were suggested.

Keywords: STEM; AG-STEM; science; technology; engineering; mathematics; integrated curriculum

Agricultural careers of the future will require more knowledge and skills related to science, technology, engineering, and mathematics (STEM) (Association of Public and Land-Grant Universities [APLU], 2009; Committee on Prospering in the Global Economy of the 21st Century, 2007; National Research Council, 2009). STEM will be critical to ensuring an adequate food supply, economic well-being, public and environmental health, security, new industries, and an improved standard of living in developing countries. Agricultural education has used inherently interdisciplinary contexts and involved each of the four STEM subjects. This can help address the stagnation of student achievement in STEM (APLU, 2009; National Research Council, 2009).

Agriculture has also faced the difficult problem of a growing population combined with environmental limits. With population projections at over 9 billion for 2050, food production must significantly increase at the same time it is shrinking its environmental footprint (Foley et al., 2011). Furthermore, The National Research Council (2009) pointed out society's major challenges,

> including energy security, national security, human health, and climate change — are closely tied to the global food and agriculture enterprise. Academic institutions with programs in agriculture are in a perfect position to foster the next generation of leaders and professionals needed to address these challenges. (p. 1)

Therefore, agricultural education should help create a 21st century workforce able to address social, economic, and environmental challenges through STEM. The National Research Council (2009) went as far as suggesting STEM be changed to science, technology, engineering, agriculture, and mathematics (STEAM). Despite the calls for increasing integration of STEM into agricultural

[1] Eric Stubbs is a Graduate Assistant in the Department of Agricultural Education and Communication at the University of Florida, 411 Rolfs Hall, Gainesville, Florida 32601, ericeric@ufl.edu.
[2] Brian Myers is a Professor of Agricultural Education in the Department of Agricultural Education and Communication at the University of Florida, 307A Rolfs Hall, Gainesville, Florida 32601, bmyers@ufl.edu.

curricula, a research gap has made it difficult to address through policy and teacher preparation. Myers and Dyer (2004) noted "studies are needed to identify the best methods teacher educators can employ to prepare teachers for this expanded role" (p. 50).

Federal policies have targeted increasing teacher efficacy and student achievement in STEM to better prepare students for a job market that requires sophisticated knowledge and skills. Concerns motivating STEM policy have included "achievement gaps between various demographic groups, U.S. student performance on international mathematics and science tests, foreign student enrollments in U.S. institutions of higher education, global STEM education attainment, U.S. STEM teacher quality, and the U.S. STEM labor supply" (Gonzalez & Kuenzi, 2012, p. 4). An overview of STEM education research by Brown (2012) concluded "more research is needed in both descriptive classroom applications for practicing teachers and in rigorous qualitative/quantitative research projects" (p. 10). Gonzalez and Kuenzi (2012) also connected increasing student achievement in STEM with positive socioeconomic outcomes.

A key part of the philosophy of STEM education, much like agricultural education, has been an emphasis on connecting content knowledge, STEM knowledge, real-world issues, and problem solving skills (Ejiwale, 2012). Interestingly, agricultural education has employed many of the same teaching methods research has suggested for STEM education. When teaching STEM, Ejiwale (2012) noted the special importance of engaging students in "motivational activities that integrate the curriculum to promote hands-on and other related experiences that would be needed to help solve problems as they relate to their environments" (p. 91). Therefore, agricultural and STEM education have been a natural combination. Indeed, school-based agricultural education (SBAE) has been so diverse the philosophy of agricultural education has emphasized the process of learning by doing over the specific content learned (Phipps & Osborne, 1988).

The explicit integration of science was first called for by the National Research Council in 1988. This drove the development of agriscience curricula, led to agriculture classes that provided science credits, and inspired studies showing how an agricultural context can improve science learning (Conroy, Dailey, & Shelley-Tolbert, 2000). Coolman (1992) noted engineering presents possibilities for solving problems, while agriculture provides a quickly increasing number of problems related to production and processing. More recently, the March-April 2013 edition of *The Agricultural Education Magazine*'s theme was using agriculture to teach STEM.

As with science, significant research into mathematics in school-based agricultural education (SBAE) has also been completed (Miller & Gliem, 1994; Stripling & Roberts, 2012; Young, Edwards, & Leising, 2008). However, less research has addressed integrating technology and engineering. This has been a problem of STEM education research and action in general (Coppola & Malyn-Smith, 2006).

Career and technical education (CTE), including SBAE, has been pushed to embrace the federal emphasis on STEM. "Agricultural education within the high school environment is becoming heavily looked upon by administrators as a way to bring relative meaning to core academic content that often seems to be a vast wilderness to so many students" (Haug, 2011, p. 7). Documenting and escalating the STEM content taught within agricultural classes may help administrators, politicians, and the public realize their value. This study has sought to contribute to the field by collecting qualitative data on how three typical SBAE programs taught STEM knowledge and skills as well as teacher and student perceptions of STEM within SBAE. In doing so, several of the aforementioned issues and knowledge gaps were addressed.

Theoretical Framework

The model of teaching and learning described by Dunkin and Biddle (1974) provided the framework used to investigate the variables in this study. Their model clarified and added detail the Mitzel model and its utility has been supported by other research in SBAE (Park & Osborne, 2004; Young et al., 2008). The division of teaching and learning into four categories of variables provided an effective way to organize the qualitative data. Relevant variables were selected within the categories: presage, context, process, and production. Presage variables are teacher-related; context variables are those related to students and the community; process variables are what happen in the classroom; and product variables are the outcome.

A conceptual model of the framework and variables has been shown in Figure 1. The presage variables chosen for study were STEM knowledge and perceptions, teacher preparation, and professional development experiences. The context variables were perceptions of STEM, demographics, and school and district support of STEM. Demographics included were socioeconomic status, gender, and race. The process variables were teaching method, level of STEM integration, and student engagement. The product variables were student achievement and student and teacher perceptions of STEM. These variables guided the collection of data through observations, interviews, and artifacts. The choice of variables was influenced by Myers and Osborne's (2005) model for strengthening academic learning in SBAE research. Literature related to the variables was reviewed to provide the necessary background for an effective investigation.

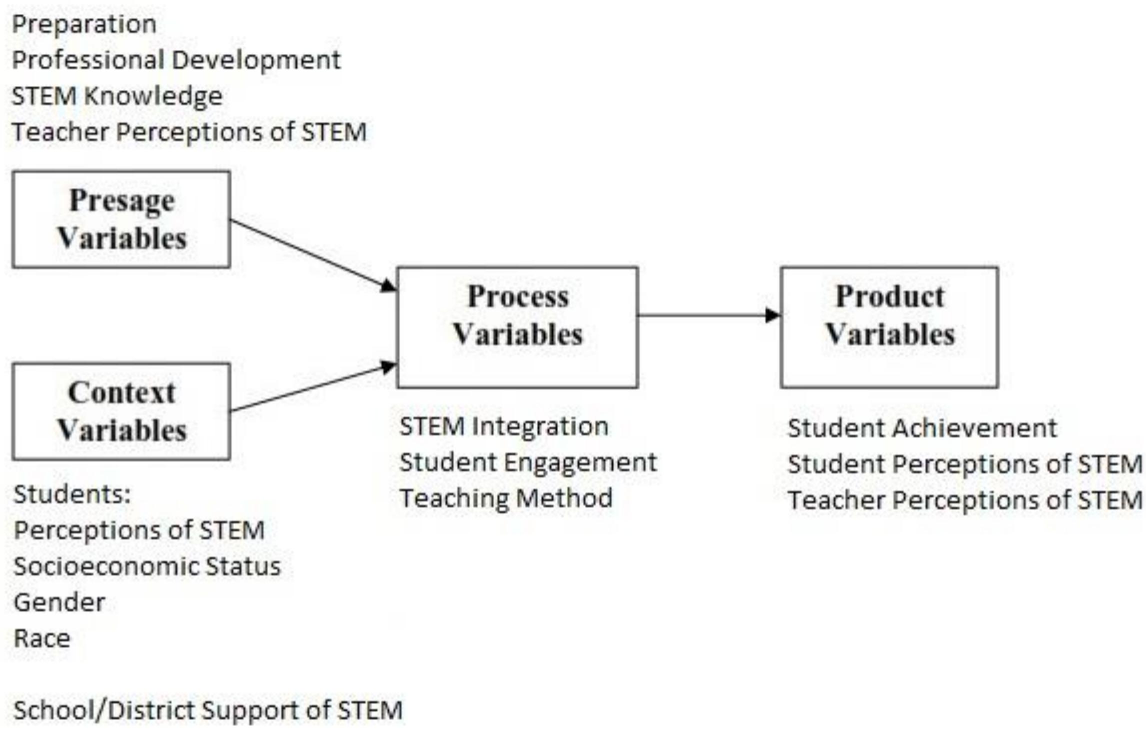

Figure 1. The variables of interest organized by Dunkin and Biddle's (1974) model.

Additionally, this qualitative research was undertaken from a constructivist epistemology. Constructivism is the idea that people construct their knowledge through experience. In this research, an effort was made to understand how the participants came to their understandings. The goal was "to come as close as possible to understanding the true 'is' of our participants' experience from their subjective point of view" (Seidman, 2012, p. 17).

Purpose and Objectives

The purpose of this study was to determine the processes, perceptions, content, and methods associated with teaching STEM in selected high school agriculture programs, and then to identify implications concerning how STEM is taught in SBAE through a multiple case study analysis. The objectives of the study were to:

1. Identify STEM knowledge and skills taught in the SBAE programs.
2. Identify the processes and methods used to teach STEM knowledge and skills.
3. Document agriculture students' and teachers' perceptions of STEM.
4. Synthesize the data using cross-case analysis to create conclusions about STEM integration.

Methodology

This case study was descriptive and used a multiple case, embedded design (Stake, 2013). The embedded units of analysis within the case of an SBAE program were the students, teachers, and curricula. Data were gathered on each separately, though also on the interactions between them. The multiple case study approach has allowed researchers to use cross-case analysis to accept or reject theoretical propositions about the phenomenon (Stake, 2013; Yin, 2003). Initial propositions concerning variables in the conceptual model were created based on a review of literature. The theoretical propositions guided the collection of data and were updated as it was gathered. The finalized propositions have been discussed in the conclusions section.

Case Study Protocol

Data were collected from five sources: direct observations, interviews, documents, archival records, and artifacts. These represented all the possible case study data sources listed by Yin (2003), except participant observation. Throughout the study, data collection followed the three principles suggested by Yin (2003): use multiple sources of data, aggregate all data into a case study database, and maintain a chain of evidence.

Detailed notes were taken during direct, reactive observations. Notes concerned the variables included in the study with a focus on STEM. A two column system was employed, with a narrow column on the right where S, T, E, or M was written when a STEM discipline was observed. Notes were taken on spoken words, body language, the physical environment, movement, and the content of lessons and activities. Discussion and questioning with students occurred during observations when appropriate and allowed by the teacher. Their perceptions, STEM learning in agriculture, and whether it related to or helped with other STEM-related courses were explored. For each case, observations were completed once a week for at least three hours and eight observations total. This led to a total of about 75 hours of observation for the whole study.

During observations, documents and archival records including lesson plans, student work, tests, textbooks, classroom décor, and district websites were examined for STEM-related content. Photos of documents and actual documents were added to the case study database. Other times, the content of classroom documents were summarized as part of the observation notes. Teachers were asked to provide documents they felt were relevant to teaching STEM through agriculture.

The teachers also participated in semi-structured interviews. The interview technique was based on the in-depth, phenomenological structure described by Seidman (2012). A three-interview series focused first on history, then current experience, and lastly reflection on meaning. The interview guide included these questions:

1. Can you describe the preparatory programs you completed before becoming a teacher?
2. How has agriculture teaching changed since you have been involved in agricultural education?
3. How does your program incorporate STEM knowledge?
4. How do students react to STEM-related content in the agriculture curriculum?
5. How do you choose which STEM-related content to include?

Probing questions were employed to ensure themes important to the teachers determined the direction of the interviews. The third interview was completed via email and served as member checking. A preliminary analysis of each case was shared with the teacher, and each was asked to describe its accuracy, how it could be improved, and reflect on the participant experience.

Other elements of the protocol were a researcher reflection log and memos. Reflection logs allow researchers to explore thoughts and biases privately. During data collection, memos were used to record ideas and emerging themes to be explored during analysis.

Selection of Cases

The three cases in this study were selected from a convenience sample frame of eight SBAE programs within an acceptable travel radius. While all the schools represented typical cases, two traits were identified that differentiated them: population density and whether or not biotechnology was taught at the school. The three programs in the study were selected for maximum variation on these traits. Maximum variation can be used with small samples to ensure a more representative investigation of the phenomenon (Merriam, 2009). All three teachers agreed and signed informed consent documents.

Analysis of Data

A strength of the case study approach has been the use of multiple sources of evidence to triangulate (Yin, 2003). Using several sources of evidence has allowed case study researchers to develop converging lines of inquiry that are validated by multiple pieces of information. Data were examined for themes through coding and for convergence around the case study propositions. This examination happened for each case separately. Then, cross-case analysis employed further triangulation to settle upon cross-case findings.

Coding of the observation notes and interviews was used to identify the major themes as well as when STEM disciplines were addressed. The interviews were transcribed and then coded in WeftQDA version 1.0.1 by the researchers. Following the process of the constant comparative method (Glaser, 1965), analytical coding was used to identify the abstract concepts and meanings within the teachers' interviews (Richards, 2009). Initial codes were the variables of interest. Other codes that emerged have been discussed in the findings. This process was completed for each case, preliminary analyses were sent to the teachers for member checking, and then the case reports were written.

The first attempt to ensure credibility, dependability, and confirmability of data and the analysis was to complete practice interviews and observations before the case study began. Credibility was ensured through triangulation (Merriam, 2009). The case study database also served to create a chain of evidence or audit trail. This, along with the detailed case study protocol, has increased the dependability (Merriam, 2009; Yin, 2003). Respondent validation was also employed to increase credibility and confirmability of the findings (Richards, 2009; Seidman, 2012).

Additionally, rival interpretations and propositions were sought from the University of Florida AG-STEM Lab. This combined two methods of increasing credibility suggested by Merriam (2009) and Yin (2003): exploring rival explanations and investigator triangulation. Transferability has been addressed by generalizing to theoretical propositions rather than to a population (Yin, 2003) and selecting cases for the maximum variation possible within the sample frame (Merriam, 2009).

Limitations and Researcher Subjectivity

The main limitations of the protocol were the lack of generalizability to a population and the effect of travel restrictions on the geographic area of the sample frame. While these limitations have suggested a lack of transferability, the data and findings have provided insight into an important phenomenon. As with any qualitative research, the experiences and biases of the researchers must also be taken into account. The researchers drafted subjectivity statements prior to data analysis. We believe agricultural education has much to gain from highlighting the STEM concepts and principles naturally found in the agriculture context and diverse possibilities for curricula exist.

Findings

The cases were named based on the population density: Rural High School (RHS), Centerpoint High School (CHS), and Suburban High School (SHS). Biotechnology tracks were offered as part of CHS's agriculture program and as a separate program at SHS. At RHS, biotechnology was briefly taught within an introductory class. Beyond the traits selected for maximum variation, several other differences existed between the cases. Rural High School had one agriculture teacher, while Centerpoint and Suburban had two. The Rural High School program had two tracks: animal science and agricultural mechanics. Centerpoint High School had animal science, biotechnology, and horticulture tracks. Suburban High had animal science, veterinary assisting, and horticulture.

Other than variables from the conceptual model, codes that emerged during the individual case analysis included: rapport, tension with elective nature, STEM careers, importance of technology, we have been doing this, jargon, textbooks, and online resources. The following case reports have briefly summarized data related to the variables in the conceptual model.

Case One Report

Mr. Olsen, the teacher at Rural High School, had nuanced and contextual perceptions of STEM. For instance, while he questioned the value of many instructional technologies, he saw technology as a driving force in agriculture. Mr. Olsen stated:

> Ag teachers have been addressing STEM for years and years. From what I can see, my lesson plans haven't changed because of STEM. I've been doing STEM my whole life. I just didn't call it STEM. It was part of what we did. It was part of our program, it was part of our curriculum. I didn't go, oh I gotta start throwing more lessons in there on math and more lessons in there on science. I guess people need to get in the classrooms and see what we're doing, and then they would understand.

He went on to discuss how agriculture classes are electives, so students have different expectations than for required academic classes. A tension existed between making classes enjoyable for students and ensuring significant STEM learning. While both were important to Mr. Olsen, building rapport with students and cultivating their interest in agriculture was his first priority.

STEM was often integrated into lectures and activities. Student engagement was consistently high. Hands-on activities were often informal. The word informal has been used here to describe hands-on activities that didn't involve data collection, an experiment, the design process, or post-activity reflective thinking. For instance, after a lecture on how to solder, the students completed an informal activity in which they soldered two pipes together. The lecture was clearly science-based but also incorporated mathematics by mentioning the increasing price of copper and its effects. Despite being informal, the hands-on activity provided an opportunity to practice kinesthetic skills.

The program had many connections to the school and community. Projects often involved partners from outside the agriculture program, such as when the agricultural mechanics class designed and built a bandstand for the school band. Experiments with preparing manure from a nearby dairy farm for vermicomposting were completed. The researchers' understanding of engineering education evolved thanks to this case and from reading more relevant literature. The two core ideas taught during introductory engineering education have been the engineering design process and the interconnections between STEM and society (Brunsell, 2012). Mr. Olsen fulfills these basic requirements of engineering education:

> Ag mechanics is all STEM. It's just, they don't see it as -- we don't call it ag mechanics STEM, we call it ag mechanics and they think that kids are down here changing oil. Well, there's a whole lot more to it. We do plumbing, we do electrical, we do welding, we do oxygen acetylene, we do brazing, we do woodwork, and it's all the math and science and trigonometry and geometry for designing and building the things we build.

Case Two Report

Mr. Greer was one of the agriculture teachers at Centerpoint High School. While the other teacher taught animal science, Mr. Greer taught horticulture and biotechnology. The program had a modern greenhouse where the plants for an annual poinsettia sale were grown. A shade area with other plants and vegetable garden were also maintained. A grant recently funded the renovation of a storage room into a biotechnology lab.

The teaching methods Mr. Greer employed during observation were lecture, discussion, Socratic questioning, laboratory work in groups, hands-on activities, book work, individual work, and call and response. STEM was heavily and explicitly integrated into the curriculum and was often reflected in the essential questions written on the board in the classroom. The first unit in the introductory class was based off of textbook materials and included a discussion concerning agriculture's relationship to population growth and age distributions by country. The biotechnology class had similar discussions and written assignments related to the way biotech innovations have affected and will affect civilization. While less mathematical in nature, these discussions clearly had students considering the economic, ethical, environmental, and agricultural effects of STEM. On mathematics, Mr. Greer said:

> I like to think that we reinforce because a lot of times I think kids believe math is just I have to know it. I have to go through it. I don't like it. So, we try to show them ways they can use it, like fertilizer percentages, parts per million. I struggle with geometry, but we will learn to measure a piece of property by pacing it. And you'll have to know the area of a rectangle, perhaps the area of a triangle, to figure the piece of property. Making our garden, we make it square. Well, we use the Pythagorean Theorem.

The laboratory activities completed by the biotechnology class involved STEM through and through. Even an introductory activity of making ice cream involved practice with STEM knowledge related to measurement, solutions, melting point, and other properties of matter. DNA extraction, gel electrophoresis, tissue culture, and many other activities were all included in the curriculum that was purchased with the laboratory equipment.

Classroom management and student engagement were sometimes a challenge compared to Rural High School. Yet the impact of STEM integration on students' abilities was still positive.

Mr. Greer provided an anecdote about other teachers noticing these improved abilities in the agriculture students:

> In biotechnology, if they are in 10th grade when we do DNA - oh wow, it just reinforces that material that they're receiving in biology about DNA. And I've heard it from the teacher side: They say, Mr. Greer, did you just do a unit on – I say yes, I sure did. Oh, the kids seemed to be engaged, they had a good conversation, they knew a lot more background than I initially thought, I just want to make sure. And I say yes, I just covered that.

Similarly, several students provided examples of how agriculture lessons supported STEM learning in other classes when prompted. Mr. Greer also told the story of a student who ended up in a STEM career at a citrus research center after completing his program and a baccalaureate degree.

Case Three Report

At Suburban High School, Ms. Aiken perceived STEM as an important but difficult aspect of teaching agriculture. Her chief concern regarding teaching STEM was the varying ability level of students, which was particularly a challenge in the introductory class. The class provided students with a science credit, which sometimes caused credit deficient seniors to see the class as an alternative to the traditional science classes they had failed. She felt STEM education was a new term to describe an old phenomenon agriculture teachers have been working with for quite some time. She discussed the many time consuming responsibilities of teachers, which was a more acute problem for agriculture teachers. She was concerned policies related to STEM education may lead to additional stress and wasted time rather than tangible improvements in teaching.

Several class sizes were large, with around 30 students. Keeping students engaged during hands-on work in the greenhouse presented a spatial challenge, as some students would only stay engaged when Ms. Aiken was nearby. She described the challenge:

> If I'm outside with the animals, we have a problem with I've got to keep my eyes on what the animal is doing and you can only have one child really working with an animal at a time, especially if it's the beginning. And so you are watching them, and the rest of the class is supposed to be participating and asking questions and watching. But, I have to be watching them, too. It's kind of like being a bus driver. You need that bus driver to watch the road, and you need somebody in that bus to watch the kids.

The researchers learned from an interview that the animal science and veterinary assisting classes involved a significant amount of technology education. The cattle at the school each had radio frequency identification (RFID) to track and log all information regarding the animals. A scanner could be used to pull the data up on a computer. This was especially relevant given the ongoing discussion of livestock tracking policy in the U.S. Ms. Aiken also used "a heat watch system to detect standing heat in cows" and said "this technology increased the success of conception through artificial insemination without using hormones." In addition, giving vaccinations provided a context through which students learned about medical technologies and performed mathematical calculations of dosages. Students learned transfer needles could be used to move liquid into the bottle of a freeze dried vaccine and dissolve it.

Mathematics was integrated through data gathering, and analysis was often completed by calculating percentages or fractions. A few students were chosen to help Ms. Aiken with the accounting by writing receipts, logging payments, and calculating totals. Ms. Aiken would verify their work before sending it to the school's bookkeeper. Economics was also discussed periodically. Word problems related to the costs of supplies, size of vaccine dosages, and other topics were completed during several different observations.

Engineering education in this program was primarily related to genetic engineering. However, the researcher also observed Ms. Aiken send a small group to fix a broken irrigation system. Although it was not made explicit, the students were responsible for designing and implementing a solution, which practiced their engineering skills.

Cross-case Analysis

In the cross-case analysis, data from all three cases were compared and synthesized. Codes developed during cross-case analysis included troubleshooting and more than STEM. While the individual reports functioned to describe the general nature of each program and its STEM teaching, this section has addressed the first three objectives directly.

The programs had several commonalities. All three teachers involved in the study had agricultural education degrees from the same land grant university and more than 20 years of experience. The teachers described a mixture of technical agriculture, education, science, mathematics, and general education coursework. Each mentioned being taught the importance of teaching agriscience. They also prioritized building rapport and caring relationships. Students were comfortable asking questions and participating in discussions.

A STEM-related activity that occurred across all cases was troubleshooting and repairing broken systems. In each case, broken equipment presented a challenge the teachers embraced by involving students in solving the problem using the design process. Without being prompted, two teachers mentioned the importance of being flexible and using troubleshooting as a STEM problem solving opportunity. The third agreed troubleshooting provided a teachable moment involving STEM when asked.

Agriscience textbooks were present in all cases but only used regularly in one. The textbooks acknowledged the necessity of integrating science, technology, and mathematics. However, as in two of the cases, most of the mathematics in the textbooks involved the memorization of numbers or displays of data. Furthermore, engineering knowledge, skills, and careers were not consistently integrated into the textbooks examined.

Another pattern was both teachers and students stated that agriculture classes integrated more than STEM; they incorporated history, reading, communication, and other subjects. The history of science has been an important aspect of science education (Matthews, 1994), suggesting the same holds for STEM. The leadership, communication, and collaboration skills taught through SBAE are also essential for STEM careers, which often involve teamwork (Ejiwale, 2012).

Objective 1: Identify STEM knowledge and skills taught in SBAE. The STEM knowledge and skills taught during the observations or mentioned in the interviews were identified through coding and broadly categorized in Tables 1 and 2. Therefore, these should be viewed as a snapshot of what the programs taught during the study rather than the entirety of their curricula. Careers were listed and discussed in introductory classes and periodically throughout the teachers' curricula.

Additionally, a list of federal STEM-designated degree programs was obtained (U.S. Immigration and Customs Enforcement, 2013) and used as another way to document the STEM content of agriculture programs. The number of degree programs for which each case provided introductory knowledge was recorded. Respectively, the cases introduced knowledge related to 40%, 46%, and 42% of the 424 federally-approved STEM degree programs. The researchers' analysis indicated a broad interpretation of agricultural curricula could incorporate knowledge related to as many as 76% of the STEM degree programs. The list and analysis can be found in Stubbs (2014).

Clearly, the cases addressed interdisciplinary STEM content. While mathematical operations were integrated infrequently at RHS, it was the only case that consistently integrated engineering. Engineering integration occurred mainly in the agricultural mechanics classes but was also sometimes observed in the other classes. Science, technology, and their connection to society were integrated almost seamlessly in all cases. Observations indicated agriculture teachers must have a significant amount of STEM knowledge simply to keep a program functioning. Hands-on skills related to scientific, technological, and measurement procedures were demonstrated by the teachers and practiced by the students.

Table 1

Science and Technology Integrated by Case

Case	Science	Technology
All cases	Agriscience; Biology (plant science, animal science); Earth science; Energy; Science history; Genetics; Measurement; Nutrition; Scientific method; Science literacy; Soil and water science	Agritechnology; Biotechnology; Computer skills; Hand tools; Measurement tools; History of technology
1		Welding; Soldering
2	Chemistry	
3	Physics	Livestock tracking; Digital microscope

Table 2

Engineering and Mathematics Integrated by Case

Case	Engineering	Mathematics
All cases	Agricultural; Genetic; Problem solving; Troubleshooting; Measurement	Algebra; Calculations; Converting measurements; Decimals, fractions, and percentages; Economics; Estimation; Measurement
1	Design process; Mechanical; Electrical; Sketching	Geometry, Trigonometry
2	Sketching	Geometry, Trigonometry
3		

Objective 2: Identify the processes and methods used to teach STEM knowledge and skills in SBAE. Teachers' processes that were identified included lesson planning and taking advantage of teachable moments with improvised STEM-related discussion and questioning. Lesson planning here refers to materially and mentally preparing to teach a lesson, procuring new lesson plans, and creating original lesson plans. On improvised STEM-related discussion and questioning, Mr. Greer said, "A natural, opportunistic teacher sees a moment, pounces on it, and tries to expand on that topic. I'm not the greatest, but I like to think that I planned some and others lend themselves just to the moment."

During informal hands-on activities in the greenhouse, Ms. Aiken would respond to student comments and questions with STEM-related dialogue. Regarding the STEM lesson planning process, Mr. Greer stated "the planning of it takes so long, it takes a lot of work up front to really plan out a good STEM unit."

Teachers often used the Internet as a source of lesson plans, many of which integrated STEM. The agednet.com website was used by two of the programs. The other main sources of curricula were teacher-created materials, teacher preparation programs, textbooks, and the FFA. FFA CDEs were referenced by all three teachers as sources of STEM integration. The Forestry CDE in particular was described as mathematics intensive by two teachers. Textbooks were used regularly only in one case. The other two teachers used the textbooks mainly for substitute days, homework, or review. Teaching methods used to teach STEM included lecture, discussion, Socratic questioning, hands-on practice, collaborative group work, formal lab work, informal lab work, the gradual release method, call and response, and individual practice.

Concerning context variables, each program had a network of support. It even extended beyond their districts through the FFA. Similarly, each district had other programs that were considered STEM programs. While all the teachers reported interactions with the community of agriculture teachers, only one teacher reported interacting with an unrelated CTE STEM program. Whether through procuring grants or helpful administration, district and school support seemed to have a tangible impact on STEM integration.

Objective 3: Document agriculture teachers' and students' perceptions of STEM in SBAE. The perceptions were outlined individually in the case reports. Overall, teacher perceptions of STEM were context-dependent. Commonalities included the perceptions that technology has had an incredible influence on agriculture and teachers must educate students about it. Despite emphasizing and teaching the value of STEM careers, all the teachers wondered whether STEM was simply a new educational phrase that might not gain long-term significance. An underlying perception identified across all three cases was the worry that too much STEM-integration would decrease student rapport. For instance, one teacher stated integrating mathematics everyday would discourage students from taking agriculture classes as electives. While he still integrated mathematics through data collection and the Forestry CDE, calculations were not individually performed by students during the observations. After witnessing calculations and mathematics-related discussions several times in a different case, the teacher was asked about doing the activities despite the dislike of mathematics he had mentioned. He then emphasized the importance and beauty of mathematics as a way of knowing and condensing information. Teachers' perceptions affected the types and levels of STEM-integration in their classrooms in a complex way.

Two of the teachers' perceptions related to engineering were muddled compared to their perceptions of science, technology, and mathematics. Only Mr. Olsen discussed engineering during interviews without prompting and used the word in his classes. His program integrated engineering education primarily through the agricultural mechanics class. Mr. Olsen continually employed the engineering process of "delimiting an engineering problem, developing solutions, and optimizing the design solution" (Brunsell, 2012, p. X).

During the interviews, the barriers mentioned by teachers were time, funding, and lesson plan resources. Teachers were also concerned about the diverse ability levels of students, and each teacher discussed the challenges presented by learning disabilities and poverty. Whether this affected the teachers' integration of STEM was unclear. Two out of three of the teachers discussed professional development experiences related to agricultural STEM (AG-STEM) at significant length. The teachers perceived workshops and FFA conventions as an important source of AG-STEM curriculum.

Student talk about STEM varied from calm confidence to boisterous pronunciations of aversion. The following quote from Ms. Aiken illustrated that teachers who integrate STEM can experience push back from students who have negative perceptions of STEM:

> Oh, I had kids yesterday ask me in my ag foundations class, because we were going over a paper they had to do - it was all math, it was word problems that dealt with medications and inventory in a veterinary hospital: Ms. Aiken, why are we doing math in here? This is an ag class. Well, there are practical reasons.

Student perceptions of and reactions to STEM integration were considered by the teachers. At some point, each teacher attempted to improve student perceptions by explaining the value of STEM learning to agricultural production. Importantly, student perceptions have often been related to engagement and achievement in observed activities (Mullis et al., 2000; Reyes, Brackett, Rivers, White, & Salovey, 2012; Weinburgh, 1995).

Conclusions

The case reports and cross-case analysis revealed much about the teaching of STEM in SBAE and the multi-faceted responsibilities agriculture teachers. Running a successful secondary agriculture program involved many responsibilities. The teachers ran extra-curricular organizations and managed small agricultural operations that raised funds for the program. In discussing the implications and recommendations based off this research, these manifold responsibilities were kept in mind.

Objective 4: Synthesize the data using cross-case analysis to create conclusions about STEM integration. The theoretical propositions with which this multiple case study began evolved through the process of gathering data. Three were accepted and supported by the literature review. Two others were accepted, and five were abandoned. The following three propositions were based on the literature review and have been supported by multiple sources of data from the cases:

1. STEM integration has a positive effect on student achievement in STEM without decreasing agricultural content knowledge.
2. Positive teacher perceptions of STEM and effective STEM integration are associated and can positively influence students' perceptions of STEM.
3. Teachers with more STEM-related preparation and professional development are more likely to incorporate STEM at higher levels.

Whether gathered through observation, student questioning, or interviews with teachers, data suggested students' STEM abilities were exercised and improved over time. Research concerning integration of individual STEM disciplines has also supported this proposition (Enderlin, Petrea, & Osborne, 1993; Parr, Edwards, & Leising, 2006; Roberson, Flowers, & Moore, 2000; Stone, Alfeld, Pearson, Lewis & Jensen, 2006). When students were asked about the connections between agriculture and other classes, several discussed how many of the activities they enjoyed in the agriculture class demonstrated knowledge they were learning in other classes. The power of experiential learning to cultivate interest and provide motivation was apparent (Kolb, 1984).

Even if teachers have negative perceptions of a discipline, they can integrate it effectively as long as it is perceived as important and useful, as exemplified by Mr. Greer and mathematics. The ability of teacher STEM perceptions to affect student perceptions was also supported by the literature review (Balschweid & Thompson, 2002; Hayden, Ouyang, Scinksi, Olszewski, & Bielefeldt, 2011). Many students' perceptions of STEM have been and can be positively influenced by activities that show them real-world applications of STEM that are relevant to their lives.

All three teachers described STEM-related preparation and professional development as influencing their level of integration. Technical agriculture classes during their baccalaureate studies provided a foundation of STEM knowledge. They all reported their agricultural education courses had addressed integration of science and technology and discussed how much more STEM had been integrated in programs since their time as secondary agriculture students. Teacher education programs that integrate agriculture and science have produced teachers who are more positive about science integration (Balschweid, 1998). Calls by researchers to continue increasing support for science integration in preparation programs (Wilson & Curry, 2011) can be understood in terms of proposition three. The other propositions accepted based on the cross-case analysis were:

4. The amount of STEM integration varies significantly between units within a program.
5. Agriculture teachers must have a high level of STEM knowledge and skills simply to keep a program functioning.

Level and type of integration was often influenced by textbook and lesson plan contents, seasonal activities, and the FFA Career Development Event (CDE) calendar. Mr. Greer had students plot poinsettia growth every fall, while integration of mathematics through forestry and land judging CDEs occurred in all the programs. The teachers also noted they integrated STEM in new ways each year, which revealed even veteran teachers make yearly changes in STEM integration.

The final proposition emerged during the study when data repeatedly indicated agriculture teachers could not successfully run a program without significant STEM knowledge and related skills. The knowledge was exhibited to students by the successful agricultural operations managed as part of the programs. Students not only witnessed the application of the teachers' STEM knowledge, they participated in it through experiential education.

Several propositions were abandoned due to scarcity of data or insufficient narrowness. While the grant funded biotechnology program at CHS suggested district support can increase a program's level of STEM integration, little else related to school or district support was observed or heard during interviews. A proposition that student perceptions would reflect teacher perceptions was rejected.

Recommendations

This study clarified the scope of STEM integration, documented perceptions of it, and revealed strengths and weaknesses of integration across the three cases. Teacher educators, agriculture textbook publishers, and curriculum developers have an increasing role to play in AG-STEM integration. These cases and other research have suggested more attention to integrating engineering and mathematics may be needed (Coppola & Malyn-Smith, 2006; Stripling & Roberts, 2012). Preservice teachers should practice developing and delivering highly integrated AG-STEM lessons using a diversity of teaching methods. AG-STEM lesson plans in textbooks, curriculum packages, and online reduced barriers associated with planning and delivering AG-STEM education for the teachers in this multiple case study, so curriculum development efforts should continue in this area.

For researchers, each of the case study propositions represents a line of inquiry that could be pursued further. The relationships between student rapport, STEM integration, and diverse ability levels were concerns of the teachers that could be further investigated. Examining the nature and extent of STEM integration required by different curriculum frameworks could also provide an important research contribution.

Activities involving the relationships between AG-STEM and society are an important way for practitioners to investigate student perceptions of STEM and connect them to real world contexts. Using such activities, teachers should aim to improve student perceptions of STEM due to the multiple benefits of positive perceptions (Reyes et al., 2012). Furthermore, the contextual and experiential approach of agricultural education is in line with research-based STEM education methods (NRC, 2009; Ejiwale, 2012). Practitioners should take advantage of this to create effective AG-STEM learning environments.

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