

Identification of Essential Integrated STEM Curriculum Implementation Components

Abstract

Measuring the factors affecting the implementation process is critical for understanding how, why, and under what circumstances integrated STEM curriculum innovations work. The overarching goal of this National Science Foundation (NSF) funded project was to design, field-test, implement, and evaluate contextualized integrated STEM learning experiences that use agricultural life sciences (AgS) as a context. To that end, we developed AgS model-eliciting activities (MEAs). MEAs are thought-revealing tasks that require student teams to mathematize real-world situations. The present study employed the iterative engineering design process guided by the innovation implementation framework to identify essential structural and interactional integrated STEM curriculum implementation components. Common Core State Standards (CCSS), teacher scopes and sequence plans, student readability level, agricultural life science contexts, culturally relevant pedagogy, and access to STEM mentors were mapped to the AgS MEA curriculum implementations. Drawing on semi-structured teacher interviews (individual and focus group), recorded teacher development sessions, and documented expert consultations, this study provides research-to-practice findings that support the effective implementation of an innovative integrated STEM curriculum for elementary grade levels. An iterative engineering design process guided by the innovation implementation framework provided a strategic iterative method to utilize teacher feedback over five AgS MEA implementations. Six structural and six interactive AgS MEA implementation components were identified. The results from this work can help mitigate the barriers researchers and teachers experience when implementing integrated STEM curriculum innovations.

Keywords: engineering design; STEM curriculum; math modeling activities; elementary level

Introduction

A problem contributing to widening the gap between students who pursue a career in science, technology, engineering, and mathematics (STEM) and students who do not is the lack of academic preparation in STEM subjects, specifically at the elementary school level. This problem was confirmed by the National Academies of Sciences, Engineering, and Medicine (NASEM, 2020), which found that roughly 75% of U.S. students were not proficient in STEM subjects such as mathematics and science at the end of 8th grade. Several factors contribute to elementary school students' success and interest in STEM. Respectively, culturally relevant pedagogy, early exposure to careers in STEM, and community connections to STEM represent a planned sequence of integrated STEM curricula (Clark, 2017; Sithole et al., 2017). Agricultural life sciences' (AgS) familiarity to students, experiential and interdisciplinary nature provide a vibrant venue of real-world settings to engage students in STEM integration (Bostic et al., 2020; Ryu et al., 2019). The integration of STEM through AgS is not a new concept for educators. As early as the 60s, school-based agricultural education (SBAE) focused on integrating science, forestry, natural resources, and food processing with career and technical education (Wang & Knobloch, 2018).

Despite a national call for an integrated STEM curriculum in K-12 education, teachers lack opportunities to participate in integrated STEM-related teacher development and the design and development of integrated STEM curricula (National Academy of Engineering and National Research Council, 2014). Without the appropriate support for teachers to learn about implementing an integrated

STEM curriculum, teachers will struggle to understand the essential components necessary to implement an integrated STEM curriculum, enhancing students' engagement and interest in STEM (Wang & Knobloch, 2018).

Identifying essential implementation components of curriculum innovations is pertinent to understanding how, why, and under what circumstances curriculum innovations work (Century & Cassata, 2014; Durlak, 2010; Hulleman & Cordray, 2009; O'Donnell, 2008; Ruiz-Primo, 2006; Sanetti & Kratochwill, 2009). Researchers acknowledge that implementing curriculum innovations is complex and includes enacting interrelated components if the implementation outcomes are fully understood. For example, Domitrovich et al. (2008) defined implementation components as "a set of features or practices that are directly related to the underlying theory of the intervention" (p. 8). Relating implementation components to an underlying theory of curriculum innovation, researchers can then operationally define implementation components according to their essential parts that lead to intended outcomes (Century & Cassata, 2014). Implementation components, referred to as building blocks, include critical program dimensions, essential characteristics, and integral parts (Mowbray et al., 2003; Wang et al., 1984). For this study, critical program dimensions are essential implementation components. Researchers agree that implementing curriculum innovations consists of crucial components that must be specifically described and measured to bolster or hinder student performance (Fullan, 1983; Ruiz-Primo, 2006; Wang et al., 1984).

Few studies have identified or explored essential implementation components of STEM education curriculum innovations at the elementary level (Levy et al., 2008; Mowbray et al., 2003). Fewer studies have explored agricultural life sciences (AgS), including health and diet, alternative energy sources, equitable green spaces, and food security/insecurity, as contexts for elementary-level STEM curricula (Mercier, 2015, Wang & Knobloch, 2018). However, researchers appear to agree that using AgS as a context to integrate STEM into teaching can support the ease of integrated STEM curriculum, especially at the elementary school level (Wang & Knobloch, 2018).

Literature Review

As a result of several educational reform efforts that emphasized STEM education (Hilby et al., 2014; Phipps et al., 2008; NAE & NRC, 2014), there are multiple calls for agricultural education to prepare students for STEM careers. For example, the National Research Council's (2009) report on *A New Biology for the 21st Century* called for students to prepare for mathematics and science careers through agricultural education. Shinn et al.'s (2003) white paper also outlined agricultural education's role in enhancing students' mathematics performance. Relatedly, results can help teachers implement integrated STEM curriculum innovations in the classroom, with low student engagement and disruptive student behavior.

The American Association for Agricultural Education's National Research Agenda for 2016-2020 listed a research priority to investigate "effective STEM integration models in a school-based agricultural education curriculum" (Stripling & Ricketts, 2016, p. 32). Dossett et al. (2019) stated, "we are in an era of scientific agriculture that combines basic and applied aspects of the traditional STEM disciplines" (p. 256). Hence, this study attempted to address calls for agricultural education to prepare students for STEM careers by implementing an integrated STEM curriculum that used agricultural sciences (AgS) contexts and model-eliciting activities (MEAs) – termed AgS MEAs.

MEAs are realistic, client-driven problems that are inherently interdisciplinary and require student teams to develop a mathematical model to solve a given situation (Diefes-Dux et al., 2008; Lesh & Doerr, 2003). Using data in real-world contexts, MEAs facilitate learning by developing students'

conceptual understandings and sense-making. MEAs require students to mathematize (e.g., quantify) information in context to develop a mathematical model as a procedure/product (Diefes-Dux et al., 2008). MEAs are thought-revealing in providing student teams an opportunity to self-reflect and provide teachers a window into students' thinking during problem-solution development.

Six principles guide the design of MEAs (Diefes-Dux et al., 2008). These design principles require that all MEAs include: (a) a model construction – a mathematical model of a procedure/product; (b) realistic context – an authentic STEM-related problem; (c) self-assessment – an opportunity for student teams to self-assess the usefulness of the model; (d) model documentation – a procedure/product description; (e) model shareability and reusability – shareability and reusability for similar purposes; and (f) a functional learning prototype – a globally generalizable or modifiable procedure/prototype.

The MEAs discussed in this study used AgS contexts to help promote contextualized learning, conceptual understanding, and encourage students to consider STEM as a career option by exploring culturally relevant real-world problems. The AgS MEAs were unique because they were culturally relevant to students' environments and focused on four significant societal challenges: health, energy, environment, and food (Bostic et al., 2020). The AgS MEAs were connected to local urban community issues and relevant across varying cultural groups. AgS MEAs required students to reflect on their situations and make connections between food insecurity versus food security, health, and diet in the context of childhood obesity, the affordance of renewable energy, and equitable access to green spaces.

AgS (i.e., health, energy, environment, and food) are interdisciplinary areas that have primarily been underexplored (Mercier, 2015) as contexts for integrated STEM curriculum innovations in elementary school settings. Producing foods, fuels, medicines, materials, and the like through agriculture involves various STEM disciplines, including physical sciences, chemical sciences, biological sciences, technology, engineering, and mathematics. Unlike some fields, which are narrowly defined, agriculture is multidisciplinary, interdisciplinary, and transdisciplinary (Vasquez et al., 2013). Furthermore, the challenges of meeting sustainable clean water, food, medicine, urban green infrastructure, and clean energy needs for over 9 billion people by 2050 situates AgS as an ideal context to explore real-world engineering-based rich problems that are culturally relevant (Wise, 2013).

Conceptual Frameworks

This study draws upon two complementary frameworks: (1) the engineering design process (National Academies of Sciences, Engineering, & Medicine, 2020; Parker et al., 2016) and (2) the innovation implementation framework (Century & Cassata, 2014; Gale et al., 2020).

The engineering design process is a systemic cyclical approach to a problem-solving method used by engineers for a design problem (National Academies of Sciences, Engineering, & Medicine, 2020; Parker et al., 2016). The iterative engineering design process guides engineers through solving problems and learning important information about the issue and possible solutions to the problem-solving process (Atman et al., 2007; Atman et al., 2005). While the term, engineering design, may vary in different educational domains, common to all definitions of the engineering design process is the iteration of multiple design phases (Capobianco, 2011; Moore et al., 2013; Parker et al., 2016).

As defined by the National Academies of Sciences, Engineering, and Medicine (2020), engineering design was characterized using five phases (Atman et al., 2007; Atman et al., 2005). The first phase is to determine the problem. Defining the problem involves moving from a vague, abstract

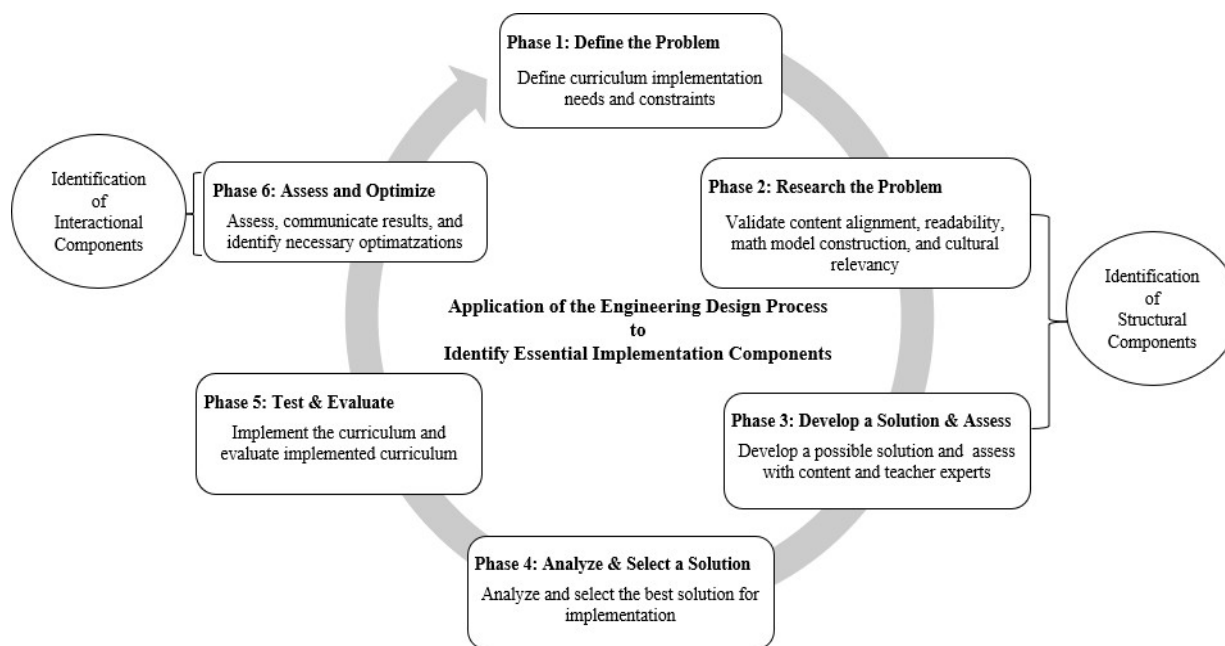
idea of a design problem to a clear, unambiguous definition of the problem. A more explicit problem definition statement will evolve as a complete understanding of the design problem's human needs and constraints are understood. The second phase is researching the situation. Gathering pertinent information about the design problem can reveal facts about the situation that can validate or redefine the problem statement through a series of questions asked and answered. The third phase is developing possible solutions to the design problem. Developing possible solutions involves generating creative new ideas to solve specified human needs and constraints. The fourth phase is analyzing and selecting a problem solution. Experts analyze and vet possible solutions during this phase, whereby the best solution is implemented. Lastly, phase five is to test and evaluate, which involves creating a fully operational solution prototype, then testing during implementation. Evaluation requires an assessment of the implementation. During phase five, design decision-making and communication are essential to developing quality solutions. The five primary phases describe an iterative, cyclical approach common to most applications of the engineering design process and enable engineers to continually enhance and improve their designs through repeated testing, analysis, and redesign (Atman et al., 2007; Atman et al., 2005).

Mapping the Engineering Design Process to AgS MEA Curriculum

This study operationalized the engineering design phases in the following ways. Phase one, defining the problem, was established by defining the integrated AgS MEA curriculum implementation needs and constraints. During phase one, the curriculum implementation ideas moved from a vague, abstract concept to a clear, strategic plan aligned with the project's objectives to include implementation fidelity. Implementation fidelity is the "extent to which an enacted program is consistent with the intended program model" (Century et al., 2012, p. 347; O'Donnell, 2008). Phase two, researching the problem, was accomplished by gathering and validating information about the AgS MEA curriculum implementation to ensure program consistency. Collecting and validating alignment of the AgS MEA content with the Common Core State Standards Initiative (2010), content readability level, mathematical model construction and content, and cultural relevancy were pertinent to ensuring implementation's fidelity. Phase three, developing possible solutions, was achieved by assessing the AgS MEA curriculum implementation content during teacher development sessions and with participating teachers of the AgS curriculum implementation. Phase four analyzed and selected a solution for implementation through a vetting session with content experts. Phase five tested and evaluated the implementation of the AgS MEA curriculum. This study called for a sixth phase, assess and optimize, to the engineering design process where the AgS MEAs were assessed for necessary optimization.

During each of the five AgS MEA implementations, teacher focus groups captured teachers' feedback about what worked and did not. The assessment part of phase six identified essential interactional implementation components and any revisions and modifications, thereby enabling the continual enhancement and improvement of the subsequent AgS MEA implementation through the iterative engineering design process. Figure 1 illustrates how this study operationalized the engineering design phases. Figure 1 also indicates that essential innovation implementation components (structural and interactional) were identified in phases two and three.

Figure 1

Application of the Engineering Design Process to Identify Implementation Components

Note. Figure one indicates structural components identified during phases two and three and interactional components in phase six.

The Innovation Implementation Framework

The innovation implementation framework can be defined as “the extent to which [curriculum] implementation components are in use at a particular moment in time” (Century & Cassata, 2014, p. 87). The framework conceptualizes curriculum implementation as complex and composed of essential explicit or implicit components (Century & Cassata, 2014; Gale et al., 2020). The innovation implementation framework identifies and categorizes two significant types of curriculum implementation components: structural and interactional. Structural components include “organizational, design, and supporting elements, which are the building blocks” (Century & Cassata, 2014, p. 88) of the curricular implementation. Structural components are divided into procedural parts (i.e., organization and curriculum design elements) and educative parts (i.e., support elements that communicate what learners need to know). Interactional components include “behaviors, interactions, and user practices during enactment” (Century & Cassata, 2014, p. 88). Structural components support procedural elements and communicate what learners need to know. Structural components inform the ways that teachers implement the AgS MEAs. Interactional components are divided into pedagogical parts (i.e., support actions expected of teachers during curriculum implementation) and learner engagement (i.e., support students with expected engagement when partaking in the curriculum intervention). Interactional components support teachers’ and students’ behaviors, interactions, and practices during implementation.

The innovation implementation framework's two main propositions were relevant to this study. The first assumption is that curriculum implementation components vary in the number and type of components and the degree to which components are explicit or implicit within an implementation

model. The second assumption is that some implementations focus more on structural components and others on interactional components (Century et al., 2012). The innovation implementation framework was used as a guide to define and categorize the identified structural and interactional implementation components across five implementations.

Purpose of the Study

The purpose of this study was to identify and characterize the structural and interactional implementation components of an integrated STEM curriculum innovation (i.e., agricultural sciences (AgS) model-eliciting activities (MEAs)). The research question that guided this study is: What are the structural and interactional components of an integrated STEM curriculum (i.e., agricultural sciences model-eliciting activities (AgS MEAs))?

Context of Study

This study occurred in the central part of the United States at a K-6 environmental magnet school in a large urban school district. The U.S. Department of Education (2004) defines a magnet school as offering a range of distinctive education programs emphasizing math, science, technology, visual and performing arts, or humanities. In the context of this study, the magnet school focused primarily on STEM education. The school comprised an 83% minority population, with 61% of students receiving free or reduced lunch assistance.

A convenience sample of seven elementary school teachers participated in this study for three years. Teachers' consent was secured through the project's affiliated university. Teacher participants received a stipend and instructional supplies for participating in the study. Participants included four sixth-grade teachers and three fifth-grade teachers ($n = 7$), representing six female teachers (one African American/Black, five Caucasian/White), and one male teacher (Caucasian/White). Years of teaching experience ranged from less than five to about 15 years. The teachers' subject expertise included English language arts (ELA), mathematics, and science. Five of the seven teacher participants completed three or more implementations of the AgS MEAs. The variance in teacher participation in the implementations is due to teacher staffing changes. Table 1 summarizes the teacher participants' demographics.

Table 1

Description of Teacher Participants' Demographics

Teacher Name	Grade Level	Subject Expertise	Years Teaching Experience	of	AgS Implementation(s)	MEA
Ms. Montana	6	Science	<15		1, 2, 3	
Ms. Tina	6	ELA	>5		1, 2	
Ms. Maria	6	ELA	<15		3, 4, 5	
Ms. Windy	6	Science	>5		3, 4, 5	
Ms. Carol	5	Mathematics	>5		1	
Mr. Sam	5	Mathematics	<5		2, 3, 4, 5	
Ms. Christine	5	ELA	>10		1, 2, 3, 4, 5	

Note. Pseudonyms are used to protect the anonymity of the participants.

Corresponding Features

Five AgS MEAs were introduced to the teachers over three school years. Each AgS MEA addressed a major societal challenge: (1) health and human diet, (2) renewable energy, (3) urban green spaces, and (4) food security and insecurity. To ensure cultural, career, and community connections to students' real-life experiences, each AgS MEA was connected to a relatable topic – a societal challenge related to local community issues, STEM careers, and cultural relevancy. All AgS MEAs were developed to adhere to the models, modeling perspective, and associative principles (Bostic et al., 2020; Lesh & Doerr, 2003) and were aligned with national standards (CCSS, 2010). See Table 2 for a list of AgS MEAs.

Table 2

Five AgS MEAs and Corresponding Features

AgS MEA Title	AgS Learning Context and Societal Challenge	Problem Statement Key Question	Example of Common Core State Standards Potential Addressed
Healthy Food Choices	Public health & nutrition related to childhood obesity-Health	How do consumers use the Nutrition Facts Label information to make healthy food choices?	CCSS.MATH.CONTENT.5.OA.A.2 Write simple expressions that record calculations; interpret numerical expressions without evaluating them.
Renewable Energy	Sustainable energy (wind, solar, & energy) - Energy	How can we harness renewable energy for us in our everyday life?	CCSS.MATH.CONTENT.5.NBT.B.7 Add, subtract, multiply, and divide decimals to hundredths using concrete models or drawings and strategies based on place value and properties of operations.
Urban Green Spaces 2.0	Equitable urban green space development - Environment	How do design and access to green spaces influence the quality of life for residents in urban neighborhoods?	CCSS.MATH.CONTENT.4.G.A.1 Draw points, lines, line segments, rays, angles (right, acute, obtuse), and perpendicular and parallel lines. Identify these in two-dimensional figures.
Food Security/ Insecurity	Urban community gardens - Food	How can a community contribute to increasing the availability of healthy food?	CCSS.MATH.CONTENT.4.OA.A.3 Solve multistep word problems with whole numbers and have whole-number answers using the four operations.
Healthy Food Choices 2.0	Public health & nutrition related to childhood obesity - Health	How do consumers use the Nutrition Facts Label information to make healthy food choices?	CCSS.MATH.CONTENT.5.OA.A.2 Write simple expressions that record calculations with numbers and interpret numerical expressions without evaluating them.

Note. The reference of 2.0 after an AgS MEA title refers to an updated version.

Methods and Procedures

This study utilized a qualitative case study (Merriam & Tisdell, 2015; Yin, 2017) approach, wherein five implementations of AgS MEAs by teacher participants represented the case. The case study design allowed for investigating a contemporary phenomenon such as integrated STEM AgSMEA curriculum innovations (the case) in its real-world context (the classroom). This case study focused on integrated STEM curriculum implementation by individual classroom teachers. This study identified a case by implementing the MEAs rather than the individual teacher. The study aimed to identify essential implementation components. Hence, the actual implementation of the AgS MEAs was our work's primary focus and unit of analysis. The implementation of five AgS MEAs was examined to identify structural and interactional implementation components. The case study was bounded by a finite time for interviews and a defined number of teacher participants available for interviews.

Data Sources

This study employed semi-structured interviews of teacher development sessions, teacher focus groups, and content expert consultations. Data sources were used to identify the structural and interactional implementation components of the AgS MEAs and identify revisions and modifications for viable implementation of the AgS MEAs. Semi-structured interviews are important sources of case study evidence (Yin, 2017). Semi-structured interview protocols allowed data to be collected using different modalities, such as making keen visual and aural observational field notes while collecting audio and video recordings. Data were gathered in two separate timeframes. The first timeframe occurred during phase three (develop a solution and assess, see Figure 1) of applying the engineering design process. During phase three, teacher development, and content expert consultations focused on identifying structural implementation components and any revisions and modifications for viable implementation of the AgS MEAs. The second timeframe occurred during phase six (assess and improve, see Figure 1) of applying the engineering design process. Teacher focus groups and content expert consultations focused on identifying interactional components and revisions and modifications for viable implementation of the AgS MEAs. Each interview type (i.e., teacher development sessions, teacher focus groups, and content expert consultations) is described below.

Teacher Development

The goals of the teacher development sessions were to: (a) conduct an explanatory demonstration of the AgS MEA; (b) engage teachers in a reflective discussion about any immediate implementation concerns; and (c) engage teachers in conversations about culturally relevant pedagogy, community engagement, and STEM career exploration. Before each implementation, teacher participants attended 45-minute development sessions for five sessions over three years. Throughout the development, teachers provided continuous feedback on the development and refinement of each AgS MEA. This feedback served a dual purpose of (a) informing the research team about the effectiveness of teacher development and (b) providing rich data from the teacher participants about their ideas and understanding of implementing MEAs. Teacher development sessions engaged teachers in discussion with the researcher about the structural components of the AgS MEA implementation. Recall that structural components include procedural elements such as organization, curriculum design, and educative support elements that communicate what learners need to know about the AgS MEA implementation. A prototype of the AgS MEA was emailed to teachers one week before the teacher development session. Sessions were held for 45 minutes and were guided by a semi-structured interview protocol to resemble a guided conversation. A structured Q&A protocol was avoided to ensure that teachers could freely discuss and identify grade-appropriate structural implementation components that conformed to students' classroom environments. The teacher development sessions began with a question to prompt discussion (e.g., "Do you have any questions about the AgS MEA

implementation?”). The sessions encouraged teachers to openly discuss the AgS MEA implementation with critical questions and feedback on the AgS MEA implementation. We then asked teachers semi-structured questions focused on structural components, including AgS MEA curriculum support material, culturally relevant meaningful engagement methods, team formation, supporting technology, AgS MEA assessment, and the general implementation plan.

Teacher Focus Groups

Teacher focus groups engaged teachers in discussing the interactional components of the AgS MEA implementations. The interactional components include pedagogical elements such as behaviors, interactions, users’ practices during implementation, and learner engagement. All interactional components engaged students through community partners, culturally relevant data sources, guided reflections, supporting technology, and team roles & responsibilities. Teacher focus groups were conducted one-day post-AgS MEA implementation, inclusive of the second data collection. Focus groups were held for 45 minutes and were guided by a semi-structured interview protocol to resemble a guided conversation. A structured Q&A protocol was avoided to ensure that teachers could openly discuss and assess the AgS MEA implementation, identify interactional implementation components, and identify AgS MEA revisions and modifications to inform subsequent AgS MEA implementation. The five AgS MEA post-implementation focus groups began with a semi-structured protocol of six questions to prompt discussion. Iterative refinements were made to the list of items comprising the post-implementation semi-structured protocol after each AgS implementation. Sample questions from the semi-structured protocol were: “What went well during the AgS MEA implementation? What did not go well? Describe the effectiveness of the AgS MEA implementation; for example, what areas or components of the AgS MEA need improvement? What were additional supports that you felt you could have used? How did team roles and responsibilities support MEA implementation?”

Content Expert Consultations

After the first and second data collection timeframes, documented content expert consultations provided specialized input on the AgS MEA implementations. Content experts included three faculty members from three research-intensive universities and three K-12 teachers. The university faculty had expert knowledge in agricultural sciences, mathematics, applied sciences, and culturally relevant education and the three K-12 teachers had expertise in science and mathematics. The K-12 teachers were licensed and received MEA implementation teacher development (~80 hours). Content experts were emailed an AgS MEA prototype before and after each of the five AgS MEA implementations. Semi-structured questions resembled an AgS MEA implementation assessment rubric and guided the content experts’ consultations. Two sample semi-structured questions were, “To what degree does the AgS MEA support all learners’ engagement in the MEA? What challenges do you perceive with implementing this AgS MEA as part of your classroom instruction?” (Bostic et al., 2020).

Data Analysis

All recordings of data were transcribed verbatim. The three research team members cleaned the transcripts by making corrections while listening to the recordings. Data analysis involved a four-step process. First, data from teacher development sessions, teacher focus groups, and content expert consultations from all five AgS implementations were analyzed using a constant comparative method (Creswell, 2014; Merriam & Tisdell, 2015). Second, data were systematically archived in two data timeframes during phases three and six of the iterative engineering design process. Phase three of the engineering design process involved collecting data from teacher development sessions and content expert consultations, which informed structural AgS MEA implementation components. Phase six of the engineering design process reported interactional AgS MEA implementation components. Phases three and six of the engineering design process informed revisions and modifications for viable

implementation of the AgS MEAs. Third, data were coded using open and axial coding (Creswell, 2014; Merriam & Tisdell, 2015). Open coding occurred by reading through the transcripts and jotting down notes or snippets from the transcripts in the margins while remaining open to data that may be potentially relevant or important to the study (Merriam & Tisdell, 2015). Snippets of data were then compared to create codes. Axial coding occurred by grouping and comparing codes with codes to create themes of essential implementation components. Finally, the researchers employed a detailed line-by-line member check of data during teacher focus groups (one-day post-AgS MEA implementation) to validate categories. Revisions and modifications identified for viable implementation of the AgS MEAs emerged during each iterative data analysis.

Trustworthiness of Findings

As Yin (2017) recommended, several strategies were used to establish the validity and trustworthiness of the findings. The researchers used member checking to ensure the transcripts captured the conversations correctly and represented teacher participants accurately. Construct validity was accomplished through multiple data sources to establish a convergence of evidence (i.e., teacher development sessions, teacher focus groups, and content expert consultations). Internal validity was accomplished by triangulating all three sources and independent researcher member checking. External validity was achieved through the iterative engineering design process to ensure replication logic among the five AgS MEA implementations; specifically, researchers sought literal replication among the five implementations (Yin, 2017).

Findings

Six structural and six interactional AgS MEA implementation components were identified. Themes emerged during reflective discussions (part of teacher development sessions) and were validated during member checking (part of the teacher focus groups). The structural components support procedural elements and communicate what learners need to know. Structural components include (a) a cover page, (b) an advanced organizer/news article, (c) discussion topics, (d) problem-solving strategies, (e) an MEA assessment rubric, and (f) an implementation plan. The interactional components support teachers' and students' behaviors, interactions, and practices during implementation. The six interactional components included (g) student mentorship, (h) problem identification, (i) culturally relevant pedagogy, (j) team roles and responsibilities, (k) reflection, and (l) supporting technology.

In what follows, we present teachers' implementation concerns and comments that led to each theme, and related teacher quotes for each theme. Tables 3 and 4 provide a description of each of the six structural and six interactional AgS MEAs.

Structural Implementation Components

Teachers in this study discussed concerns about having a guiding document that would briefly introduce the AgS MEA's learning goals and supplies needed. Teachers' comments included the following: "What is the goal of the AgS MEA?" "How do we know what supplies will be required for the final AgS MEA presentation?" "What state standards do the AgS MEA address?" Teachers agreed that a cover page (a) was needed to provide guiding information for the AgS MEA. Teachers expressed the effectiveness of utilizing a news article to present the AgS MEA content and topic. Examples of teachers' comments included the following: "I thought beginning with the news article helped draw the kids in." "Yeah, they thought about the news article throughout the AgS MEA." "I think to a certain degree, students could relate their home experiences to the news articles." Teachers agreed that

having an advanced organizer/ news article (b) helped present the AgS MEA content, topic, and culturally relevant data-driven material. Teachers expressed concerns about the layout of questions and answers designed to assess students' knowledge from reading the news article. Teachers commented that "the readiness questions and answers do not appear to connect students to the news article or the problem to solve." "How can we incorporate culturally relevant content into the assessment?" "If you are not a teacher familiar with stimulating classroom discussion or preparing kids for discussion, things may not go well." Teachers agreed that discussion topics (c) helped present culturally relevant data-driven material and thought-provoking discussion prompts whereby teachers could better assess students' comprehension of the subject matter. Problem-solving strategies were a concern. Teachers were concerned that students would not understand where to begin solving the problem or what steps to take when problem-solving. Teachers commented, "My students were unsure what steps to take in solving the problem." "Students did not have any concept of what they should look for in the problem statement." "There could have been more structure, like deciding the outcome of what the students were going to solve." Teachers agreed that problem-solving strategies (d) helped students understand the problem, develop a strategy, and communicate a solution to solve the problem. Assessment of the entire AgS MEA was a concern. Teachers requested a means for assessing students' problem-solving skills, mathematical model construction, content comprehension, and final solution presentation skills. Teachers' comments included: "How can we assess if students comprehend the MEA content?" "We have no idea how to assess students' final presentations." "Should we assess students individually or as a team?" The assessment rubric (e) provided teachers with specific criteria for assessing students' performance with the AgS MEA. The final structural component of concern was a plan to implement the AgS MEA. Teachers expressed concerns about implementing the AgS MEAs without a guide to help them map the MEA to instructional and project goals and objectives. Teachers stated, "Figuring out how much time it takes to teach each part of the MEA and organize community partner visits is confusing." "I'd like to have a plan for instruction." "How will we know if we are implementing the MEA according to the research project's expectations?" The implementation plan (f) supported a smooth and timely implementation by outlining implementation procedures. Table 3 describes the six structural AgS MEA components.

Table 3

Structural AgS MEA Implementation Components

AgS Components	MEA	Description
Cover Page (a)		The cover page included the AgS MEA title, fundamental question, student learning goals, guiding documents to help teachers align the AgS MEA with state standards, information about team formations, and recommended supplies.
Advanced Organizer (b)		The news article included AgS MEA-related content reading based on local current events, culturally relevant data-driven material, websites of reference material, informational images, technical terms, and thought-provoking discussion prompts. Each news article underwent a Flesch-Kincaid readability test (Kincaid et al., 1975).
Discussion Topics (c)		Discussion topics included culturally relevant content supported with data sets.

Table Continued

Problem-Solving Strategies (d)	Problem-solving strategies include four steps, i.e., (1) understanding the problem, (2) developing a strategy, (3) applying the strategy, and (4) communicating a solution.
MEA Assessment Rubric (e)	The assessment rubric consisted of measures to assess the quality of the student team's final presentations on team formation, cooperative learning, and mathematical model construction.
Implementation Plan (f)	Implementation plans included planning prompts for MEA daily activities, the time required to complete the activity, and materials.

Note. Described are A through F structural components.

Interactional Implementation Components

Teachers expressed concern that students were not making strong connections to STEM careers. Teachers shared the following concerns: "My students do not understand how to identify STEM careers. For example, because they have a parent that works at a hospital, they think their parent is a nurse." "I think it would be great to see young people who have started college that can answer questions like, why did I select this STEM field, how did I get interested in this field, or at what point in high school did I start looking at college or what did I need to learn." Teachers agreed that having professionals from STEM fields guest lecture would provide students with real-world experiences of STEM professions. Student mentorship (g) allowed STEM professionals to share their professional journeys from a wide range of STEM fields. Teachers expressed concerns about students' understanding of the problem statement objective. Teachers' comments included the following: "Maybe students could use a little more background knowledge." "Some students had no idea what the task was." Six prompts were developed to help students identify the problem. Teachers agreed that problem identification (h) was instrumental in providing teachers and students with a structured process for understanding the problem's knowns and unknowns and how to draw diagrams that indicate fundamental relationships of the problem. The teachers expressed concerns about connecting the AgS MEA content to students' lives. Examples of teachers' responses include the following: "I think it would be interesting or beneficial if we could somehow incorporate the problem into students' lives;" "One idea is to have students track relevant daily life activities;" and "Students' struggled with the problem because it was not a part of their 11- and 12-year-old reality." Culturally relevant pedagogy (i) supported teachers with a better understanding of how to enact culturally relevant teaching practices, understand the pedagogical connections between culturally relevant teaching, meaningful student engagement, community engagement, and STEM career exploration. Teachers shared concerns about students' team formation, lack of cooperative learning experiences, and nonparticipation by some students. Teachers' comments included: "I had kids that were doing nothing, absolutely nothing. They were not trying; they had no idea how to do the math." "Giving roles and responsibilities to each team member gave ownership to students." "They took the roles and responsibilities seriously – it was an accountability system." "I was surprised that students remembered their role and seemed to understand." Team roles and responsibilities (j) were instrumental in creating a robust, cooperative, and competitive nature among student teams. Teachers agreed that a system to define and assign student team roles and responsibilities guided the development of student teams and defining roles and responsibilities. Teachers were concerned that due to students' lack of experience with cooperative learning, some students were engaged in "off-task" activities and had no self-regulation skills. Teachers shared the following insights: "Students continue to engage in off-task behaviors during the

implementation period.” “I think the reflections and thinking about thinking will help the student to reflect on what they’ve learned comprehend what is happening as opposed to trying just to write it down” “Reflection helps students remain on task.” Reflection prompts (k) gave teachers a window into how students conceptualized the problem to solve individually and as a group. Teachers requested supporting technology to assist with AgS MEA background knowledge and final solution presentations. Teachers noted the following suggestions: “Students like the visual stuff.” “Supporting videos serve as a great starting point.” “Students struggle to understand or visualize certain terms. Using the computer to Google terms is helpful.” “Students struggle to connect specific STEM careers with the MEA topic.” Supporting technology (l) provided teachers and students with a more agile, versatile, and practical learning environment. Table 4 outlines the six interactional AgS MEA components.

Table 4

Interactional AgS MEA Implementation Components

AgS MEA Components	Description
Student Mentorship (g)	Student mentorship was provided by in-class visits from STEM professionals who shared their professional journeys from various fields, including civil engineers, nutritional scientists, agriculturalists, food scientists, learning scientists, and city planners.
Problem Identification (h)	Problem identification included six prompts: (1) what is the setting of the client’s problem? (2) what is the goal to achieve? (3) explain your initial idea for a model; (4) list the steps (descriptions and procedures) you will use to make an effective model; (5) list the variables in your model; and (6) how you will document the model.
Culturally Relevant Pedagogy (i)	Culturally relevant pedagogy included teaching practices reflective of students’ diverse backgrounds, cultural competence, and critical consciousness.
Team Roles & Responsibilities (j)	Team roles included project manager, project designer, materials manager, and communication manager.
Reflection (k)	Reflection allows students writing time to reflect on the problem to solve, model development, and team interactions.
Supporting Technology (l)	Supporting technology included Google Slides, YouTube, web browsers, and electronic databases.

Note. Described are G through L interactional components.

Discussion

MEAs, by nature, are contextual pedagogical tasks that require active learning strategies framed by sound curriculum organization and design. With that said, there is no surprise that this study’s findings exemplified implementation components that reflect tenets of contextual teaching and learning. Principles of contextual teaching and learning include interdependence, self-regulated learning, culturally relevant pedagogy (anchoring teaching and learning in students’ diverse life),

multiple contexts, and authentic assessment (Johnson, 2002; Sears & Hersh, 1998). All the contextual teaching and learning principles are represented in the AgS MEA structural and interactional implementation components identified in this study using an iterative engineering design process and the innovation implementation framework.

For example, interactional AgS MEA implementation component team roles and responsibilities supported cooperative learning through interdependence. After students were assigned team roles and responsibilities, teachers reported that student nonparticipation decreased, and student motivation and accountability increased. The implementation component of reflections promoted the contextual tenet of self-regulated learning. Here, students were given a notebook inclusive of thought-provoking questions that guided students through a process of self-observation, self-evaluation, and self-reflection (Andresen, 2008; Blomhøj, 2008), which motivated students to define, explore, and plan during problem-solving. These metacognitive experiences helped students to develop problem-solving strategies. The problem identification implementation component also promoted the contextual tenet of self-regulated learning while providing teachers with criteria to help students define the problem. Through a group or self-reflection, students answered questions about the problem. Problem identification also provided students and teachers with a method to work through getting unstuck when solving a problem. Culturally relevant pedagogy promoted the contextual tenets of anchoring teaching and learning in students' diverse life by addressing cultural relevancy and learning in multiple contexts. Research states that the top factors contributing to STEM success and promoting interest in STEM among underrepresented students in K-12 are culturally relevant pedagogy and community connections to STEM through mentorship (Clark, 2017). The AgS MEA content was developed using culturally relevant pedagogy, and students received mentorship for STEM careers through interactions with local industry and participating universities (community connections). Culturally relevant pedagogy supported teachers to understand better how to enact culturally relevant teaching practices, understand the pedagogical connections between culturally relevant teaching, meaningful student engagement, community engagement, and STEM career exploration. The advanced organizer/news article also promoted culturally relevant pedagogy. It served as topic and culturally related content reading based on local current events and research to introduce the AgS MEA problem. Ausubel (1960) wrote extensively about advanced organizers as critical learning strategies that provide a framework for learning. An advanced organizer provides relevant anchoring ideas, organization, clarity, and distinguishability of new ideas. The implementation component supporting technology promoted the contextual tenet of authentic assessment by challenging student teams to demonstrate skills and competencies gained by applying their knowledge to realistic situations and making connections through higher-order thinking.

Conclusions, Limitations, and Implications

Identifying integrated STEM curriculum implementation components through the iterative engineering design process using the innovation implementation framework involved an iterative process of expression, test, and redesign, which provided the research team with a continuous formative assessment of implementation fidelity. Working with the teacher participants to identify essential implementation components supported overarching program outcomes and mediated three main programmatic barriers to implementation (i.e., time, technology, and communication). The interactional implementation components identified in this study (i.e., student mentorship, problem identification, culturally relevant pedagogy, team roles and responsibilities, reflection, and supporting technology) are innovative to MEAs and illustrative to mediating programmatic barriers to implementation.

Limitations

A limitation of the current study was the variability of teacher classrooms. Based on initial observations, it was clear that each classroom experienced different instructional and school-based challenges, including a lack of teacher expertise, low student engagement, and disruptive student behavior. As we continued working with the teacher participants, it was clear that the feedback they provided simultaneously served as the necessary and urgent structures the teachers needed to successfully and productively implement the AgS MEAs. This is a testament to the need for these components for AgS MEA implementation and applying the engineering design process as a systematic method to gather and utilize iterative and constructive teacher feedback. A classroom's context can be a useful lens for understanding how implementation components may influence classroom complexities that may affect teaching and learning. Analyzing how specific implementation components may influence classroom complexities could provide viable insights into enacting pedagogical practices that promote equitable outcomes for students and teachers.

Implications

This study illustrates a model for teacher success when implementing an innovative integrated STEM curriculum. Key implications of the implementation model are a framework that supports collaborative efforts between teachers and researchers to leverage the respective strengths of data collection, data analysis, and overachieving project outcomes where an innovative integrated STEM curriculum is concerned. Furthermore, the interactional implementation components identified in this study reflect an innovative approach to implementing an integrated STEM curriculum. Future research is critical to investigating the influence of various implementation components on student outcomes, such as STEM attraction, STEM retention, and STEM diversity, especially at the elementary school level. Research of this nature is necessary because studies show that students begin to choose a specific career at the elementary school level, which becomes more challenging to change as they age (Edwin & Prescod, 2018; Auger et al., 2005).

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