Utilizing Three-Dimensional Science Learning and Situated Instruction to Increase the Adoption of Sustainable Knowledge and Practice Among Rural Agriscience Students.

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INTRODUCTION

Three-Dimensional Science Learning and Agricultural Decision-Making. Documents such as the NRC *Framework for K-12 Science Education* (NRC, 2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013) advocate for three-dimensional science learning as a means to improve students' decision-making, among other goals. The goal of more informed decision-making is particularly applicable for topics that affect public interest like public health, the environment, and the economy (Rudolph & Horibe, 2016).

Decision-making in agriculture is especially pertinent, as over 70% of the contiguous US is used for agriculture and private forestry (Merrill & Leatherby, 2018). Rural agricultural landscapes contain much of the nation's wildlife habitat (NRCS, 2020) and serve crucial roles for issues such as climate change mitigation, renewable energy production, and food security (Lal, et al., 2011). Conventional agricultural production practices generally have unsustainably high consumption rates of natural resources and are increasingly maladapted for threats posed by climate change; maintenance of the industry status quo threatens the capacity to maintain sufficient levels of food production in the coming decades (Lengnick, 2015). Thus the manner in which rural students are prepared to make informed decisions as potential future agriculturalists has significant consequences for the public interest.

Challenges Inherent in Science Education in Rural Schools. While over a third of US schools are found in rural areas (Harmon & Schaftt, 2009), these districts face unique challenges that receive far less attention in academic literature compared to schools in other settings (Miller, Scanlan, and Phillippo, 2017). While the *Framework* notes that rural agricultural students' experiences often support deeper reasoning and sense-making about the natural world (NRC, 2012), rural school districts routinely struggle to attract and retain qualified science teachers (Barton, 2012). Like their urban counterparts, schools in rural America are generally disadvantaged in comparison to suburban schools in terms of poverty and test performance. (Logan & Burdick-Will, 2017). Efforts to improve rural students' performances in science and other subjects are often hindered by cultural considerations; rural residents are prone to questioning the capacity of those without legitimate rural identities to fully understand or appreciate the nuances of the problems that affect issues like education in rural areas (Miller, Scanlan, and Phillippo, 2017).

Three-Dimensional Science Learning in School-Based Agricultural Education. School-based agricultural education can potentially bolster rural science instruction while also attending to important social interactions in rural communities (Hains, Hansen, & Hustedde, 2017). There are over 8000 high school agricultural education programs found predominantly in rural areas of the United States, enrolling over a million students per year (Jackman & Schescke, 2014). Agriculture as a topic entails large amounts of scientific content, and agricultural education that specifically emphasizes science instruction in an interdisciplinary fashion is commonly referred to as *agriscience* (Barrick, *et. al.*, 2018).

Most secondary agricultural education programs in the United States utilize a three-component instructional model (Croom, 2008). This instructional model, known more commonly as the Three Circle Model, is typically portrayed as a Venn diagram to illustrate the overlap between these three components (Roberts & Ball, 2009). This model stipulates that formal secondary agricultural education should be comprised of a) classroom and laboratory instruction, b) community-based career learning opportunities (known as supervised agricultural experiences, or SAEs), and c) participation in an agricultural youth organization, such as the National FFA Organization. This instructional model results in a level of situated community-based engagement that is not commonly found in core science classes.

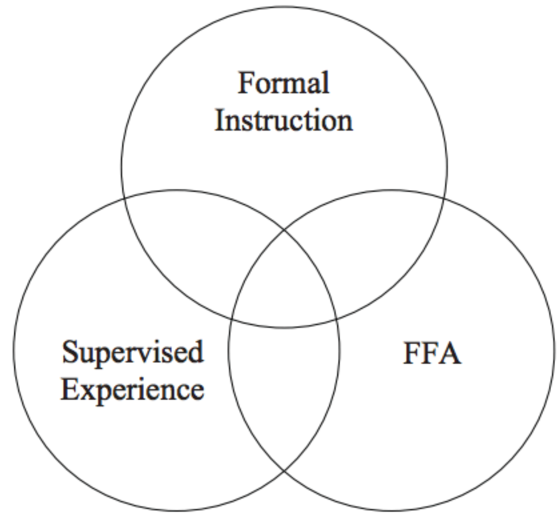


Figure 1: Three Circle Model of Agricultural Education (Croom, 2008)

The objectives of agricultural education overlap significantly with the educational objectives of documents such as the *Framework* and NGSS, especially with regard to the goal of more informed practice for issues of public interest. In particular, the mission statement of agricultural education states that the subject exists to prepare students for "successful careers and a lifetime of informed choices" in agriculture (FFA, 2019). The agricultural education instructional model may provide both unique affordances and challenges with regard to strengthening student outcomes related to three-dimensional science learning; this paper explores those affordances and challenges.

PURPOSE STATEMENT

This paper addresses both the design challenges inherent in creating and implementing a NGSS-aligned secondary agriscience curriculum and empirical findings that emerged from case study data during the enactment of this curriculum in two secondary agriscience programs. This curriculum, called the *Future of Agriculture Curriculum for Teaching Sustainability* (or *FACTS*) is designed to scaffold and assess students' three-dimensional engagement with phenomena in a manner directly relevant to management decisions made in rural agricultural landscapes. The ultimate purpose of this curriculum is to enable more informed practice among future agriculturalists, particularly in regards to increasing the adoption of more sustainable knowledge and practice for decisions made in rural agricultural contexts.

This project is connected with the *Carbon TIME* Project, which has the general goal of supporting environmental science literacy. This can be defined as "preparing students to use scientific knowledge and practices in their decisions about environmental issues" (Anderson, *et. al.*, 2018, p. 1030). This curriculum was developed through support from a Graduate Research Fellowship from the National Science Foundation and is serving as the basis for my doctoral dissertation work. I am conducting this design-based research (DBR) in order to achieve two general goals:

1. Apply principles of instructional design to develop a curriculum that responds to the special challenges of NGSS-aligned agriscience instruction.
2. Refine the curriculum through an iterative design process based on responses of teachers and students.

The remaining sections of this paper begin by describing the challenges that constrain the design of an NGSS-aligned curriculum. This is followed by a summary of the key design principles as they were enacted in the *FACTS Natural Resources* curriculum in response. I conclude with a discussion of insights that emerged as a result of the empirical findings during implementation in two case studies.

CHALLENGES OF DESIGNING NGSS-ALIGNED AGRISCIENCE CURRICULUM

While implementation of three-dimensional engagement with phenomena is challenging across all science content, alignment of agriscience instruction to NGSS presents special challenges. I describe three noteworthy considerations below.

Challenge 1: Competing Purposes of Science and Agriculture Instruction. High school agricultural education is generally offered as a Career and Technical Education subject (US Dept. of Education, 2019). The primary purpose of CTE subjects is to provide students with the skills needed to succeed in specific careers and to prepare them to navigate through the post-secondary training needed to enter a given career (OCTAE, 2016). As such, NGSS-aligned agriscience instruction addresses multiple (and sometimes competing) educational objectives. While documents such as the *Framework* allude to the need for science instruction to support more informed decision-making, agricultural education is usually obligated to primarily support industry and workforce needs (Budner-Smith & Boyd, 2018). This creates a need for compromise between the goals of sense-making and reasoning with more pragmatic considerations for local workforce preparation. Given that agricultural instructors generally face greater expectations for time commitment (Sorensen, McKim, & Velez, 2015), the additional challenges of implementating NGSS in agricultural education classrooms can present significant obstacles.

Challenge 2: Alignment to Multiple Academic Standards. The National Council for Agricultural Education developed national Agriculture, Food, and Natural Resources (AFNR) academic standards to guide the development of state and local instructional expectations (Doeing, 2018). The most recent version of these standards was developed and released in 2015 (Sands, et al., 2019). While adoption of these standards is entirely voluntary, they are meant to reflect a set of high-quality, rigorous expectations for what a secondary agricultural student should know and be able to do as a result of a particular course of study in the subject (Doeing, 2018).

NGSS-aligned curriculum for use in agriscience classrooms must also align to standards at the state or national level (or both). While the national AFNR academic standards are ‘crosswalked’ with NGSS, the manner in which these standards are aligned does not make the importance or need for three-dimensional learning opportunities explicitly evident. The difficulties of aligning to two different sets of academic standards with varying stances on three-dimensional learning (among other considerations) also serves as a significant obstacle in adoption and implementation of NGSS in agriscience classrooms.

Challenge 3: Cultural Considerations. Rural communities are often marked by strong social connections and an increased tendency to dismiss suggestions that appear to have an “outsider” positionality (Miller, Scanlon, & Phillippo, 2018). This can result in something of an insular culture in rural agricultural contexts that can reinforce identity-based approaches to sense-making and decision-making. This is also evident at the secondary and post-secondary levels for agricultural education, where teaching, scholarship, and research are often conducted in an isolated fashion; even the field's leading publication, *Journal of Agricultural Education*, generally exists separately from the rest of educational research (Hains, Hansen, & Hustedde, 2017).

Agriculture instructors frequently frame their work in ways that can be defensive about production decisions. For example, the National Association of Agricultural Educators conducted 17 interviews in 2018 and 2019 with prominent agricultural instructors about how they perceive their roles as teachers (NAAE, 2019). Many of the interviewees provided responses similar to Steve[1], who viewed his chief role as an instructor as preventing students from becoming "adults who despise our industry, simply because they do not understand it." The majority of agricultural instructors express motivation to incorporate science into their instruction, but most also lack the preparation to do so effectively (McKim, Velez, Lambert, & Balschweid, 2017).

Research-based recommendations for improvements to agricultural practices must also attend to the needs and expectations of local producers. The broad systemic recommendations of agricultural researchers generally do not easily align with the day-to-day realities of production agriculture (Rasmussen, *et al.,* 2016). This was evident in my prior work in which I investigated how agriculturalists perceived threats to future food production (Kohn, 2019). Many of the agriculturalists framed their perceived threats in terms of control and influence on how they make decisions in agricultural production, as opposed to what is generally more of systems-level perspective of threats among most academics.

This suggests that in order for an NGSS-aligned curriculum to be effective for the purposes of increasing adoption of more sustainable knowledge and practice among future agriculturalists, the curriculum must support outcomes that are responsive to the background, needs, and expectations of local agriculturalists and local agricultural instructors. This often requires utilization of an "adaptive management" approach, which emphasizes collaborative development of pragmatic solutions in an iterative manner that is sensitive to complex inter-related needs at local, regional, and global scales (Wilbanks, *et al.*, 2010). The Three Circle Model of Agricultural Education, which explicitly entails community-based learning opportunities, may provide unique affordances achieving the goals of NGSS-aligned instruction in rural agricultural communities.

KEY DESIGN PRINCIPLES AND THEIR ENACTMENT IN THE *FACTS* CURRICULUM

The *FACTS* curriculum consists of NGSS-aligned instruction intended for use in high school agricultural classrooms. I designed this curriculum to enable more informed decision-making among future agriculturalists through three-dimensional engagement with phenomena in a manner relevant to rural agricultural contexts, particularly in regards to ecological sustainability. Currently the *FACTS* curriculum consists of a sequence of two courses. The first course, *FACTS Natural Resources*, is an agroecology course that emphasizes habitat management decisions in rural agricultural landscapes. The second course, *FACTS Horticulture*, addresses the sustainable management of crop productivity through practices that support soil health and microbe biodiversity. While the initial version of *FACTS Natural Resources* is completed and available online (www.factsnsf.org), the *FACTS Horticulture* course is currently in development.

[1] Name changed for privacy.

Summary of Curricular Design Considerations. The *FACTS* project, like *Carbon TIME*, is meant to support the role of teachers in assessing and scaffolding students' three-dimensional engagement with phenomena. In the case of *FACTS*, the intent is for teachers to support specific outcomes in agricultural contexts. These outcomes include career preparation as well as adoption of more ecologically sustainable production practices. A number of key considerations were important in developing the *FACTS* curricular design in order to achieve these goals. The research basis for these considerations are summarized in space below.

Productive Disciplinary Engagement: Engle & Conant (2002) describe a series of progressions for student engagement in instruction, culminating with what they call *productive disciplinary engagement.* They describe this as a level of student engagement that enables increasingly sophisticated claims over time in a manner that raises new questions, prepares students to identify previously-unseen connections between concepts, and/or design solutions to satisfy a goal. In regards to the adoption of sufficiently sustainable agricultural production methods, all three of these outcomes are necessary. As such, Engle and Conant's (2002) work provides something a guide and a framework for evaluating the *FACTS* curricular strategies.

Purpose of Models and Investigations in FACTS: School-based agricultural education does more to emphasize career preparation and informed decision-making than the replication of the work of scientists and engineers. As such, the subject's objectives for students often reflect what Feinstein (2011) calls "competent outsiders"— more emphasis is placed on preparing students to use existing scientific knowledge and practice in an informed manner than on replicating the novel investigative work of scientists.

In developing the *FACTS* curriculum, I chose to prioritize student use of explanatory models to identify problems and develop solutions. This reflects a shift from *reasoning about models* to *reasoning with models* (Passmore, Schwarz, & Mankowski, 2017). Most weekly units feature a pre-existing explanatory model and scaffold student preparation to successfully apply it to localized agricultural contexts as opposed to having students use investigations to create the explanatory model independently. Weekly units generally culminate in community-based exercises in which students reason with pre-existing explanatory models, and use these models to address unknown questions and/or design solutions.

Cognitive Apprenticeships: Instructional reforms based on the *Framework* and NGSS are predicated on the notion that improvements to science literacy will result in more informed decision-making (Rudolph & Horibe, 2016). However, some have questioned the extent to which classroom-based instruction can transfer to non-classroom considerations. For example, Feinstein (2011) argues that individuals rarely frame decisions in terms of scientific concepts. This reflects the earlier findings of Tversky and Kahnemann (1974), who found that individuals generally rely more on heuristic devices and trial and error when making decisions regardless of their levels of scientific literacy. Brown, Collins and Duguid (1989) argued that traditional classroom instruction is too abstract to be effective for supporting contextualized decision making; rather, "cognitive apprenticeships" that place learning in authentic contexts better aligns to empirical evidence about learning and cognition. Lave and Wenger (1991) expanded on this to argue that most meaningful learning occurs outside of classrooms through opportunities for individuals to gain legitimate peripheral participation in particular communities of practice.

Because agricultural education's Three Circle Model explicitly incorporates community-based apprenticeships, this served as an ideal opportunity to blend situated aspects of learning with a three-dimensional science classroom. These apprenticeship experiences (known as *Supervised Agricultural Experiences, or SAEs*) were explicitly addressed during classroom learning opportunities. For example, each weekly unit concludes with scaffolded opportunities to connect the unit concepts to future career intentions. Students are provided with opportunities to identify discrepancies between the stances they have assumed as a classroom and what they may have encountered during "un-curated" interactions with surrounding community members. These opportunities serve as a means for students to engage in structured sense-making and reasoning, with the instructor modeling performances of how students can use evidence and explanatory models to resolve and address opposing stances.

Social Languages Inside & Outside Science Classrooms: James Paul Gee (2005) contends that language is inextricably linked to identities and social practices, and is intimately connected with the process of learning science. Gee argues that science classrooms must broaden the roles of language in students' lives in order to achieve classroom objectives, shifting students' reliance on "lifeworld" language (that which they use in their own personal lives) towards a version of professional social language commonly used within science. Gee argues that the inclusion of this language in classrooms can either be predominantly verbal or situated; i.e. while traditional science instruction emphasizes verbal science social language in that students memorize generalized rote terminology, there is also situated science social language in which terminology is closely associated with specific contexts and applications.

Gee's asserts that meaning in language is intimately linked to prior experiences. Gee identifies what seems to be an implicit causal mechanism in that comprehension is dependent on language acquisition, which is heavily tied to identity. For example, the manner in which an ecologist uses language to make meaning for considerations in rural landscapes (through terms such as species richness, carrying capacity, and ecosystem services) is quite different from the considerations an agriculturalist is most likely to emphasize (such as soil fertility, bushels per acre, and net annual profit). If an ecologist and an agriculturalist utilize primarily different languages as a result of different identities, the stances of each are likely to be incomprehensible to the other to some extent. This can present daunting challenges for teaching agroecology to diverse student audiences.

Gee's writing also provides guidance in enabling the acquisition of new language and identities in order to support increased comprehension across contexts. Gee (2005, p. 28) takes a strong stance that "social interaction and dialogue of a certain sort are also crucial to the acquisition of any social language whatsoever," including scientific language. Instruction that only occurs in traditional classroom environments is unlikely to sufficiently prepare students to utilize scientific language and concepts when making decisions. Proficiency in scientific language is dependent not just on learning scientific concepts, but also on grounding learning and instruction in scientific language and concepts in authentic contexts. Furthermore, this instruction must occur under highly-scaffolded conditions in order to support widely-ranging student needs. Gee concludes his 2005 work by asserting that scientific preparation depends on opportunities to engage with individuals with expertise, and to utilize social language within the "midst of practice and discussion" (p. 36).

Summary of Curricular Structure. In order to support the utilization of the considerations described above in a manner that aligns to both NGSS and the AFNR academic standards, I found it to be valuable to adopt a particular curricular structure that entails weekly units grouped into three sections.

Unit Sections Format: Agricultural decision-making often requires considerations across multiple contexts and scales. While agriculturalists rarely engage in structured investigations in a manner similar to that of scientists or engineers, they do depend on a wide-ranging variety of data and indicators to make decisions (Rasmussen, *et al.,* 2016). To support this objective, weekly units in each class were grouped into sections. Each section concludes with comprehensive assessment activities in which students develop explanations or design solutions for authentic local scenarios. The *FACTS Natural Resources* curriculum is divided into three sections:

- *Atoms to Ecosystems*: students first address the differences between matter and energy before applying these principles to explain processes at the atomic and cellular scales. Students then investigate how ecosystem function is dependent on biological processes at the cellular scale, using it to explain how and why biodiversity changes as environments become warmer, wetter, and sunnier as a result of the 10% rule. Students conclude by using these models to predict, assess, and explain differences in species richness and abundance between the edge and interior of a local habitat.
- *Causes of Extinction*: students determine how the four leading causes of reduced biodiversity (habitat loss, invasive species, pollution, and overharvesting) can be understood through pre-existing explanatory models related to natural phenomena. After applying these models to scenarios relevant to local contexts on a weekly basis, students conclude by conducting a risk assessment on a local habitat. After determining which explanatory models apply to threats facing their local habitat, they work in teams to design a feasible solution that can be implemented as part of the class. They conclude by engaging in evidence-based argumentation to determine which option to utilize.
- *Sustainable Societies*: students conclude the course by analyzing individual and societal factors as they pertain to the explanatory models used to address losses to biodiversity. Students then design a personal campaign to explain, measure, and improve the biodiversity and carrying capacity of a local habitat.

Weekly Unit Format: Most *FACTS* units follow a scaffolded approach that came to be known as the *Five-Day Week* (although teachers often take more than five days to complete a unit).

- On Day 1, students briefly engage in reasoning about models through a Data Dive activity. Students are presented with case study data and are asked to engage in reasoning and sense-making activities, with discourse occurring on an individual, group, and whole-class basis. Students should recognize the limitations that they have in addressing these concepts using their everyday language, demonstrating the need for more precise and sophisticated forms of science social language.
- On Day 2, students engage in scaffolded instruction that provides core information related to an anchoring phenomenon and a related pre-existing explanatory model. Students compare their initial ideas to the existing explanatory model, and use evidence-based argumentation (supported through teacher talk moves) to deepen their reasoning about how the explanatory model relates to the anchoring phenomenon.
- On Day 3, students engage in a collaborative investigation that is meant to support their developing abilities to reason with particular explanatory models in specific agricultural and environmental contexts.
- On Day 4, students are guided through a review and assessment (usually a mixture of forced choice, short answer, and essay questions).
- Students conclude a unit on Day 5 with community and career connections; these are activities meant to help students apply course topics to personal and/or localized contexts.

Example Unit - Habitat Loss: The *FACTS Natural Resources* course focuses on decisions that primarily affect wildlife habitat located the non-production areas of rural agricultural landscapes (such as forest and prairie habitats). Habitat loss is addressed in the second unit of the second section. At this point, students have completed the *Atoms to Ecosystems* section and should have more proficiency in reasoning about ecological phenomena across scales from a systems-level perspective. The Habitat Loss unit immediately follows the introductory unit on species extinctions in which students use evidence about the causes of species extinction to develop explanations as to how human activity is related.

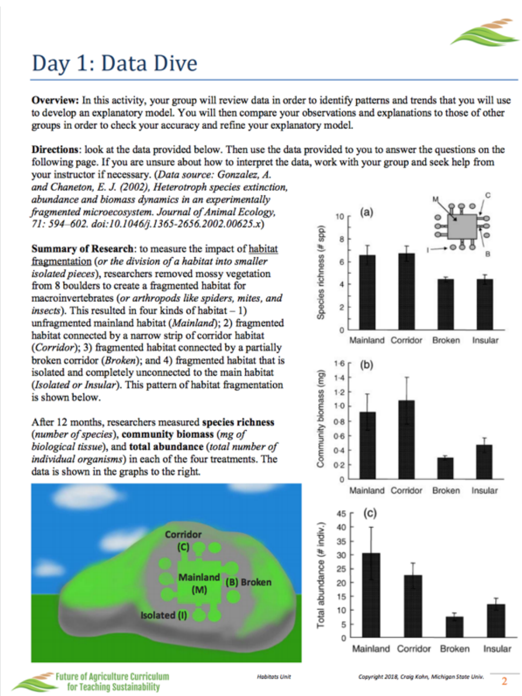
The habitat loss unit scaffolds student engagement in the following three-dimensional performances:

a. Explain the relationships between levels of biodiversity, carrying capacity, ecosystem services, and the human activities such as agricultural production, transportation, and shelter.

b. Predict the ramifications of different land management options on the carrying capacity and ecosystem services of habitats in rural agricultural landscapes.

c. Evaluate land management options in regards to the tradeoffs between ecological, economic, and social considerations.

d. Design land management options for rural agricultural landscapes that balance the need for profitable agricultural production while also supporting biodiversity, carrying capacity, and ecosystem services for habitats found in rural agricultural landscapes.



Day 1: Data Dive

Overview: In this activity, your group will review data in order to identify patterns and trends that you will use to develop an explanatory model. You will then compare your observations and explanations to those of other groups in order to check your accuracy and refine your explanatory model.

Directions: look at the data provided below. Then use the data provided to you to answer the questions on the following page. If you are unsure about how to interpret the data, work with your group and seek help from your instructor if necessary. (*Data source: Gonzalez, A. and Chaneton, E. J. (2002), Heterotroph species extinction, abundance and biomass dynamics in an experimentally fragmented microecosystem. Journal of Animal Ecology, 71: 594–602. doi:10.1046/j.1365-2656.2002.00625.x*)

Summary of Research: to measure the impact of habitat fragmentation (*or the division of a habitat into smaller isolated pieces*), researchers removed mossy vegetation from 8 boulders to create a fragmented habitat for macroinvertebrates (*or arthropods like spiders, mites, and insects*). This resulted in four kinds of habitat – 1) unfragmented mainland habitat (*Mainland*); 2) fragmented habitat connected by a narrow strip of corridor habitat (*Corridor*); 3) fragmented habitat connected by a partially broken corridor (*Broken*); and 4) fragmented habitat that is isolated and completely unconnected to the main habitat (*Isolated or Insular*). This pattern of habitat fragmentation is shown below.

After 12 months, researchers measured **species richness** (*number of species*), **community biomass** (*mg of biological tissue*), and **total abundance** (*total number of individual organisms*) in each of the four treatments. The data is shown in the graphs to the right.

Like most *FACTS* weekly units, this unit utilizes the *Five-Day Week* structure. On Day 1, students begin with a Data Dive. After the teacher introduces the unit driving questions, students work in teams of four to analyze and interpret data from Gonzalez and Chaneton (2002) on changes to insect biodiversity that result from intentional micro-habitat fragmentation. Students work independently and in small groups to develop their initial ideas using everyday language at first to describe how and why changes to habitat size and connectedness affected species richness, species abundance, and total biomass. Students are then provided opportunities to engage in convergent whole-class discussion that is designed to help students recognize the explanatory power of this experiment in regards to how habitats are managed in rural agricultural landscapes.

On Day 2, student groups are provided with a presentation that describes the Island Biogeography Model as well as relevant vocabulary that supports deeper and more sophisticated reasoning about habitat fragmentation and degradation. The instructor can choose to utilize whole-class, small group, or individual discourse to support students as they address accompanying discussion questions. An example of these questions includes the following: “What is a habitat disturbance? What is habitat succession? How are these concepts similar and how are they different?” At the end of Day 2, teachers are prompted to have students revisit their initial explanatory models that they developed on Day 1 and note any corrections or changes that they feel are necessary in light of this new information.

On Day 3, students visit a local habitat to conduct a habitat risk assessment. Using specific terms from the previous lesson (such as fragmentation, corridors, edge, etc.), students are guided in applying the Island Biogeography Model to determine how the carrying capacity and ecosystem services of the local habitat might be impaired. Students are then asked to design potential solutions and defend their ideas with reasoning.

On Day 4, students are provided with a guided review session followed by a weekly assessment. Teachers can choose either a multiple choice or essay option; I generally encourage teachers to use the multiple-choice format as a take-home assignment or a voluntary ungraded quiz. The essay and short answer quizzes generally reflect more three-dimensional performances, making them more valuable as a form of assessment. Examples of essay questions including asking students to design a plan to maximize the carrying capacity of a local habitat as well as hypothesizing how participation in a federal farmland habitat restoration program might affect the biodiversity, carrying capacity, and ecosystem resilience of nearby habitats.

Day 5 consists of career and community connections. Students are first asked to reflect on their experiences with the unit and identify how different considerations might relate to their future careers. At this point, students should have already completed a career profile in which they identify a future career and determine their most applicable path after high school graduation. As a course requirement, students must complete a minimum of 15 hours of community-based career experiences (known as *Supervised Agricultural Experiences*, or *SAEs*) outside of regular classroom instruction. Because the Habitat Loss unit occurs during a timeframe provided for SAEs, students use the remainder of this class period to gain specific forms of career preparation (such as writing cover letters in this case).

Throughout the *Causes of Extinction* section of units, students are provided with a variety of explanatory models that they can use to explain how and why losses to biodiversity occur as a result of specific kinds of human activity. At the end of this section, students take part in the Habitat Improvement Project. This is an expanded version of the Habitat Risk Assessment in which students must determine which explanatory models can be used to identify and explain threats to a local habitat. Students then are guided in using their analysis to develop solutions to improve the biodiversity, carrying capacity, and ecosystem services of this habitat in small groups. After each group formally presents their ideas, the class uses evidence-based argumentation to determine which solution is the most feasible and appropriate.

EMPIRICAL RESEARCH METHODS

Design-Based Research as a Means to Address Unique Challenges. Due to the challenges inherent in designing curriculum that meets the needs and expectations of agricultural instructors, I opted to use Design-Based Research (DBR) to structure my investigation. DBR allows researchers to develop specific solutions for real-world considerations through iterative collaborations with educational practitioners. DBR is a valuable methodological tool for improving an understanding of a theoretical construct in a "messy reality" like education while simultaneously generating practical solutions (Abdallah and Wegerif, 2014). My work is reflective of the five phases of DBR as described by Kim *et al.* (2015). These include: (1) (re)defining a problem, (2) planning action, (3) implementing, (4) evaluating, and (5) specifying findings.

The DBR methodology was used in varying ways over the period of the past three school years in order to design the *FACTS* curriculum. Qualitative interviews (Kohn, 2019) with agriculturalists and agricultural instructors provided insights into the kinds of challenges and expectations inherent in developing this kind of curriculum. These interactions also provided opportunities for testing aspects of the curriculum in a stand-alone fashion which enabled the planning and initial development of the curriculum. During the 2018-19 school year, the *FACTS* curriculum was piloted by a cooperating agricultural instructor, whose feedback during the initial weeks provided detailed insights that resulted in further revisions to the curricular design. This pilot study also provided preliminary data on the impact and effectiveness of the curriculum on student decision-making and provided insights into the feasibility of implementing this curriculum in high school agricultural classrooms. This pilot study was also important for refining and improving the data collection methods. During the 2019-2020 school year, data collection was expanded to include multiple case study sites, providing a broader feedback that resulted in deeper insights into the challenges and affordances inherent in this work.

Study Participants. The data used to support this paper's arguments were collected in case studies involving two different agriscience teachers and their students in two states. Both teachers were recruited through the National Association of Agricultural Educator's *Communities of Practice* curricular-sharing website. They expressed interest in this project due to prior experience using curriculum that I had developed. Each of these participants and respective case study schools are described below. The names of individuals and towns are pseudonyms.

- Mrs. E. has six years of teaching experience with teaching licenses in agriculture and biology. She teaches in Lanesville, a small rural town of 1300 a half hour north of the state capitol of a Midwestern state. Mrs. E. piloted the *FACTS Natural Resources* curriculum in the fall semesters of 2018 and again provided data in 2019.
- Mrs. B. has five years of teaching experience with a teaching license in agriculture. She teaches in Shoehaven, a small rural town of 1000 three hours west of the state capitol of an eastern state. Mrs. B. implemented some components of the *FACTS* curriculum last year, but did not take part in data collection until the 2019-2020 school year. Mrs. B. is also piloting the *FACTS Horticulture* course, which is currently in development.

Data Sources. In addition to my own experiences, I used five primary forms of data collection to address research questions inherent in this work. These include a three-dimensional pre- and post-assessment, student focus group interviews, teacher interviews, classroom observations, and focus student classwork. The conclusions that I present in this paper were primarily drawn from teacher and student interviews. The assessments and classroom observations served as a source of triangulation for these conclusions.

Data Analysis. For the purpose of this paper, I reanalyzed existing interview transcripts with the case study teachers and focus students. I began by identifying and cataloging relevant excerpts that referenced the challenges of implementation, personal sentiments about the curricular approach, and evidence of perceived challenges and successes. I also noted incidences in which participants' responses were particularly relevant to key design considerations. I identified significant statements from these sources that provided particularly valuable insights and used these to establish the narratives that led to the conclusions presented in this work in accordance with recommendations from Creswell (2014). It should be noted that this work is ongoing and that the results presented here are still preliminary. Data collection will continue to occur through January 2021, followed by more robust and thorough data analysis. This paper primarily serves as an opportunity to reflect on the motivation for specific design considerations inherent in the work of developing a NGSS-aligned agriscience curriculum.

Researcher Positionality. As a former secondary science and agricultural educator with ten years of classroom teaching experience, as well as a lifetime of experience in the agriculture industry, I have a strong interest in how classroom science instruction could be effective for enabling more informed practice among agriculturalists. As a current Ph.D. candidate in both science education and environmental science, and as one of the authors of the national Agriculture, Food, and Natural Resources academic standards, I find myself in a unique intersection of both insider and outsider statuses in regards to agricultural education. This positionality provides me with affordances that help me to appreciate the extent to which NGSS and AFNR considerations overlap, and how to navigate between subjects and between academic and practitioner environments.

PRELIMINARY FINDINGS

In this section, I will use evidence primarily from student and instructor qualitative interviews to argue for the necessity and value of specific curricular design strategies for *FACTS*. I will begin by summarizing the initial challenges that emerged during the implementation and revision stages, and will describe specific strategies that we collaboratively developed in response. I will conclude by providing evidence of the effectiveness of these design considerations for supporting the three-dimensional engagement of students in making informed decisions in authentic considerations.

Preliminary Curricular Development. The initial design structure for the *FACTS Natural Resources* curriculum was drawn largely from my prior experiences in developing agriscience curriculum as a high school agricultural instructor. At this time, I collaborated with other instructors, agricultural professionals, and education researchers in the process of developing my own curriculum. These curricula were posted on the National Association of Agricultural Educators' *Communities of Practice* resource-sharing website where they gained exposure to a wide audience of agricultural instructors. Metrics provided by NAAE showed that over a third of registered users have accessed my original Natural Resources curriculum for prospective use in their own classrooms since the latest version was published in 2015. Personal communication (such as email) from individual teachers with questions about implementation also indicates widespread usage. This suggested that adopting a similar curricular model in the *FACTS Natural Resources* curriculum could be useful for meeting the needs, norms, and expectations of agricultural instructors.

Student Struggles with Vocabulary. To fully support three-dimensional science learning, I needed to partially revise my original curricular model as it predated both the *Framework* and NGSS. In particular, I reduced the emphasis on content, increased the role of investigations, and broadened student use of model development and refinement across systems and scales in order to better enable students' three-dimensional engagement with phenomena. However, feedback from the teacher and students in the pilot study revealed that these modifications were resulting in significant challenges and obstacles for enabling productive disciplinary engagement. In particular, Mrs. E. (the pilot study teacher) found that students couldn't articulate their ideas in a sufficiently thorough manner, and needed additional scaffolding in order to develop more precise and accurate descriptions of phenomena. Mrs. E. described modifications she adopted in our second instructor interview of the pilot phase:

> "Uh, we changed things a little bit this week. First I started out with vocabulary. I put the vocabulary [into a quiz]…so then they could go through and, and practice their vocabulary. I think that they could better define biomass [and] biodiversity, because in the beginning they were getting confused between biodiversity and biomass and bio... you know, and everything that seemed similar to them."

I was initially hesitant about this change, especially given the fact that Mrs. E's initial approach seemed to contradict some of the expectations that accompany NGSS-alignment. Through iterative collaboration, we developed a protocol for including vocabulary in a manner that encompassed more than simple rote memorization and supported student recognition of relationships between concepts. It soon became apparent during interviews and analysis of student work that as result of these modifications, students were more capable of making increasingly sophisticated explanations about the relationships between concepts such as biodiversity, ecosystem services, and human activity.

It is important to note that the expanded emphasis on vocabulary was ultimately for the purpose of improving students' three-dimensional engagement with phenomena as opposed to the goal of rote memorization. Gee (2005) uses the term *verbal science social language* to refer to instruction where students generally memorize terms and definitions in a rote fashion. Conversely, I sought to develop protocols for vocabulary that were more reflective of Gee's notion of *situated science social language*. Specifically, I attempted to engage students in authentic activity using specialist language to address problems and design solutions. Gee suggests that the *verbal* emphasis on rote memorization has only limited value for when scientific language is needed within a specific context. Conversely, *situated* scientific language is a precursor to the level of comprehension needed for reasoning and problem-solving.

What eventually emerged through our collaborations was something of a pragmatic hybrid between verbal and situated social science language. After demonstrating the limitations of everyday language for sense-making and reasoning, students are introduced to verbal science social language to initially scaffold broad student engagement. Increasingly, students are guided towards an emphasis on situated science social language as they gain more comfort and proficiency with these terms. This alludes to the challenges inherent in navigating the tension between scaffolding student performance while also attending to meaningfulness. The more accessible the language, the less meaning and relevance it has, whereas the more meaningful the language, the greater the need for time and resources to support student engagement. The progression described here was an attempt to obtain the best of both worlds.

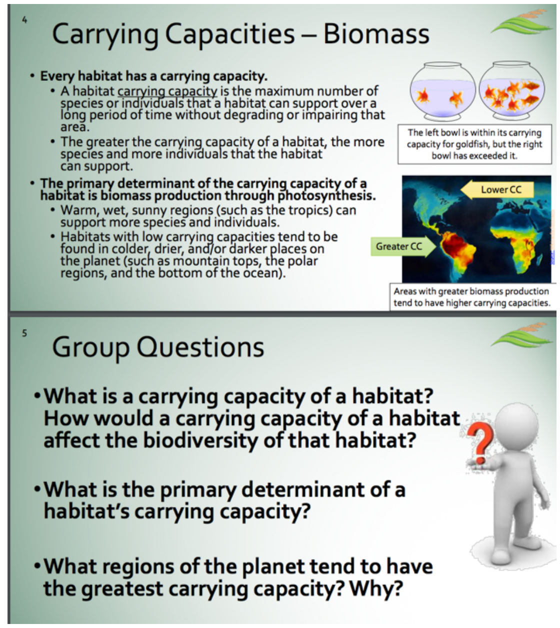
Scaffolding Student Reasoning About Phenomena. During interviews the following week, both the instructor and students reported difficulties that emerged in the goal of contextualizing phenomena in terms of localized agricultural considerations. While both the students and teacher found this contextualization to be both motivating and supportive of deeper levels of engagement, it also required students to address larger amounts of content and practices in a relatively short amount of time (especially given that most agriscience courses are usually semester-length electives). While I repeatedly considered reducing the number of units, this option was dismissed by the case study teachers. They explicitly argued that the existing units were all necessary for achieving the course objectives.

I initially provided students with some direct content in PowerPoint slides and provided them with separate questions designed to clarify individual concepts, relationship between concepts, and how these considerations related to a specific pre-existing explanatory model (such as the Island Biogeography Model during the habitat loss unit). The teacher supported sense-making discourse with a mixture of small group and whole-class discussions. However, even with this level of direct instruction, students were still overwhelmed, as was evident in this rapid exchange between focus students:

> Interviewee 5: When you're going over the slides, you have to take time to like stop and--
> Interviewee 1: …be like, "Wait, did we even cover this?"
> Interviewee 5: You don't know where you are.
> Interviewee 2: It's just harder to follow is what they're trying to get at and it's a lot more question based and it is like you're looking at [crosstalk]
> Interviewee 1: You can like actually find the information. Especially, when it has like those headers. It's like, "This is this part. This is this point."
> Interviewee 3: You take less time, to like figure things out rather than--
> Interviewee 4: It is good having the questions in there otherwise people are just like, "Where's the work?"
> Interviewee 5: Sometimes, it's like you don't have [your ideas] all the way correct so then if you look for a test you could be looking at the wrong stuff.
> Interviewee 1: Sometimes, I'll answer a question wrong and then like I'm afraid that I'm studying for the test wrong. I feel like I didn't hit all the points in the question--
> Interviewee 4: Some questions are good but more [assistance] like in a help-based thing or like more complete notes with a few questions scattered in there [would help].
> Interviewee 5: It could be like questions at the end.
> Interviewee 4: Maybe have slides' material already down there, [with] a question about the slide.

This exchange and others demonstrated that students were struggling in a shift from more traditional forms of direct science instruction to which they were more accustomed. Students were now expected to not only to understand concepts but also recognize the relationships between concepts and reason about their application to authentic contexts. This represented a major shift from their prior classroom science experiences. While students essentially were asking me to give them more rote versions of science curriculum, this would have interfered with my goal of engaging them in reasoning and sense-making as a means to improve decision-making.

Based on this feedback, the instructor and I decided it was necessary to develop highly-scaffolded group discourse prompts. This entailed shifting the emphasis from broad over-arching questions about phenomena on Day 1 to very detailed and contextualized questions on Day 2. These questions were then provided on PowerPoint slides immediately after descriptions of content. For example, students are introduced to the concept of carrying capacity in the habitat



loss unit in the PowerPoint (*see right image*). In the following slide, students are prompted to work in small groups to rephrase their own definition of carrying capacity, determine how it is related to the biodiversity of that habitat, identify determinants of carrying capacity, and reason why different regions of the planet have varying levels of carrying capacity.

These changes are aligned with recommendations from Gee (2005) in that students need clear scaffolding when initially utilizing science social language. Gee suggests that unless there is explicit support for helping students to see how they and other students interpret content and form arguments, it can lead to achievement gaps between high- and low-performing students.

This is also reflective the curricular strategy described previously of increasingly shifting the emphasis of instruction from everyday language to verbal science social language to situated science social language. As students are guided in utilizing increasingly situated language, they are also supported in applying that language to increasingly contextualized scenarios in their local communities and personal lives.

Scaffolding Student Engagement with Scientific Practices. Scaffolding also proved to be helpful in supporting student engagement with scientific practices. Students generally needed additional assistance and preparation for productive disciplinary engagement, as even explicit instructor modeling of the desired performances was insufficient to adequately support student engagement. In response, I increased the scaffolding for student investigations using prompts, sentence-starters, and direct questions (such as: *How is this conclusion supported by this data? What specifically suggests that your claim is accurate?*). This improved productive student engagement, as summarized in the excerpt below:

> Mrs. E.: The kids love the data dive on Day 1. Instead of having, you know, just like 'Here are these questions we're going to try to answer from what you already know', [you gave] them a starting point. I think you did that based on what the kids said the week before. They love that, like, 'give me a little activity to show what I do know and then maybe question what I don't know'.
> Interviewer: So do you feel like in the first couple of units, it was too much of a reach for them to try to...?
> Mrs. E.: Yes. They needed to be brought in with baby steps.

Mrs. E's comments here demonstrate what was a turning point in how I began to utilize explanatory models in the curricular design. Initially, I had intended to emphasize the use of prior knowledge and open-ended investigations in order for students to develop explanatory models to address contextualized agricultural decisions. However, based on teacher and student feedback, I shifted towards providing students with scaffolded opportunities to reason about pre-existing models after their initial engagement with the data dive. Students were then guided by the curriculum and instructor support in a manner reflective of cognitive apprenticeship during the Day 3 investigations. Specifically, this reflects the idea that instruction should “enculturate students into authentic practices through activity and social interaction” (Brown, Collins, & Duguid, 1989, p. 37).

For example, during the habitat loss unit, students were provided with the Island Biogeography Model as a means to explain how the size and connectedness of habitats affected their carrying capacity. Students gained proficiency using specific terms (such as *edge, interior, corridors*, etc.) in order to deepen their capacity to reason in a more precise fashion. During the Day 3 investigation, the teacher was prompted in how to model and coach student performances in a nearby habitat. Students were then supported by the curriculum to identify aspects of the Island Biogeography Model in this habitat, reason about its impact on considerations such as carrying capacity and ecosystem services, and support their conclusions with evidence. Students concluded by designing solutions to improve the carrying capacity of this habitat and defending their group’s ideas through evidence-based argumentation.

Effectiveness of Design Considerations. By the end of the pilot year, and during the second year of classroom testing (involving two case study sites at this point), both the teachers and students reported generally positive sentiments about the curriculum, and expressed a strong desire to continue using the curriculum. Both Mrs. E. and Mrs. B. provided explicit observations of improvements to student ecological content knowledge, such as this example from Mrs. B.:

> “Their written responses to the group questions have improved significantly in terms of both the vocabulary that they're using and just relating it to other concepts. What I saw on the biodiversity and ecosystem space was their grasp on the human-managed ecosystems and understanding - they recognize that human-managed ecosystems are trying to do as much as they can with one ecosystem service and realizing that it's at the expense of others.”

Mrs. E. also noted that students were developing a strong proficiency in recognizing the interrelationships between ecological concepts. This was particularly evident to her on the midterm exam, where students were able to effectively draw connections between *Carbon TIME* questions that they had never seen and concepts that they had learned through the *FACTS* curriculum.

Results from the student focus group interviews also suggest that the curricular strategies supported deeper reasoning among students about the ramifications of different rural land management options (including decisions that affect rural habitats in agricultural areas as well as management decisions for crop and livestock production). In the early interviews, focus students struggled to identify specific threats to future food production, especially in regards to ecological considerations. Their proposed solutions for reducing threats to agricultural production generally reflected a lack of understanding of ecological concepts; most recommended solutions that emphasized improving technology or expanding the use of conventional industrial food production.

By the later focus group interviews, students were providing responses that explicitly addressed ecological considerations and addressed conceptual models about relationships between biodiversity, ecosystem function, and human activity, such as this explanation that a student provided:

> Interviewer: What do you see as being the greatest threats to food production between now and 2050?
> Male Participant 1: I think that scientists, researchers, and farmers all need to figure out how to balance being able to use more farmland to feed more people and not destroy ecosystems and limit biodiversity to the point that it hurts the environment more than it helps.
> Interviewer: Can you go in more detail?
> Male Participant 1: Through the lack of biodiversity, it'll limit the services that we get from the ecosystems through water pollution from runoff and that sort of thing.

Both instructors found that situated community-based components of the curriculum were among the most important aspects for achieving the intended outcomes of the course. For example, when Mrs. E. was asked recently what changes could be made to the course to maximize adoption of more informed practices, she immediately responded, “More outside of the classroom stuff,” arguing that the more students were in their communities as part of the course, the more that students applied the course knowledge and practices to their decisions. This corresponds to Gee’s (2005) assertions about the importance of situated language acquisition. Specifically, Gee stipulates (p. 23) that acquisition of language depends on “access to and simulations of the perspectives of more advanced users of the language in the midst of practice.” Interestingly, Mrs. E. also found value in more verbal science social language. It seems plausible that verbal science social language may be a stepping stone between students’ initial reliance on everyday language and their eventual proficiency in using situated science social language in these real-world settings.

This notion is supported by observations from both instructors that their students were connecting the course content to broader considerations outside of the classroom. Mrs. B. suggested that the *FACTS* curriculum was especially effective with her “traditional ag students” from production agriculture backgrounds:

> “…they're getting it in terms of the environmental science and of, “This is what we can do to work with our soil and conservation.” Some of the students work on multiple farms and they're seeing, “This is why we can't do just whatever we want as a farmer.”

This capacity for transfer was explicitly evident in Mrs. E’s classes as well. For example, like many agricultural programs, Mrs. E’s students manage a school-based experimental field. Mrs. E. noted that students in the *FACTS Natural Resources* course were already adopting changes to the manner in which they planned to manage this field:

> “We have some equipment grants this year, [and] already they were talking about, "We're going to use our grain drill this year, and we aren't going to disc this year. We're going to spray and then we're going to drill it in." Then one person was like, "Yes, but then we're still spraying. So what's that doing to the environment?” “Yes, but then we're no-tilling.””

To clarify, the students decided to adopt a no-tillage management plan for this field in order to reduce the risk of erosion and nutrient contamination in area surface water. This requires the use of specialized equipment that can plant seeds without using forms of tillage such as plowing and disc harrowing. Because a key function of tillage is eliminating weeds, an herbicide application is usually necessary to support sufficient crop performance. Mrs. E's description of this exchange is noteworthy because it is evidence that students are reasoning about these practices in a deeper and more systemic fashion, and are weighing the tradeoffs between ecological sustainability and the production benefits of different management options. This is also noteworthy because while research has demonstrated that practices like no-till can be implemented with little or no loss in income (or even gains to income in some cases), full utilization of these more sustainable options has been sparse among American farmers as a whole (Mulla, Birr, Kitchen, & David, 2008).

DISCUSSION

In this paper, I have described my experiences in developing a NGSS-aligned agriscience curriculum intended to increase the adoption of more ecologically sustainable practices among future agriculturalists. This has provided an opportunity to explore questions regarding how to design three-dimensional science learning in a manner that prepares students to be both citizens of their rural communities and advocates for sustainable practices. The evidence from this work suggests that providing students with forms of direct instruction (such as high levels of scaffolding as well as practice in reasoning with precise vocabulary in increasingly contextualized settings) was helpful for supporting students in achieving productive disciplinary engagement in the course. Furthermore, having teachers scaffold the adoption of situated science social language and coach performances that enable more informed decision-making supported students' application of curricular knowledge and practice to authentic scenarios. Finally, both teachers acknowledged the importance of the situated aspects of the course for enabling the transfer of informed knowledge and practice from classroom to real-world considerations.

We also encountered notable setbacks and challenges during the implementation of this curriculum as well. Both instructors noted that there was a potential of decreased enrollment as a result of adopting this course. Mrs. E. in particular faced pushback from some of her students, especially seniors who felt that this agriscience course was "supposed to be easy, [but] was more difficult this year. I actually have kids dropping after this semester because they thought it was too hard…" Both instructors alluded to needing time to allow a culture change to take place within their program. Mrs. B. also described push-back from some community members. She estimated that while 50% of local farmers would be supportive of this curriculum, some "are still stuck in the '70s and '80s" and are reluctant to acknowledge evidence that some conventional agricultural practices are insufficiently sustainable.

The situated learning opportunities in the course (particularly SAEs) could also work against some of the objectives of the *FACTS* curriculum. Mrs. E. noted that "If they're working for somebody who does it the conventional way and not a new environmental system, they defend that side," later adding, "You want to make sure that you approve shadows. I have found that. Absolutely. I think they learn their basis there and that gets them either excited or not excited about it." Notably, Mrs. B. did not witness these kinds of challenges to the same extent with her students' SAE experiences. It is unclear whether Mrs. B.'s greater emphasis on resolving ideological conflicts between classroom and SAE experiences through scaffolded evidence-based argumentation on Day 5 might be responsible for this.

The evidence from *FACTS* case studies could provide useful insights for classroom-based secondary agriscience. First, it now seems evident that my initial narrow interpretations of the

Framework and NGSS were counterproductive for achieving the goal of more informed decision-making in authentic contexts. Curriculum that emphasized broad, open-ended investigations created what were often insurmountable barriers for enabling the intended level of productive disciplinary engagement in the course. Regardless of their prior experiences with NGSS-aligned instruction, case study students reported that the increased structure and scaffolding of the *FACTS* curriculum supported improvements to their sense-making and reasoning abilities. Evidence from assessment data and classroom observations supports these conclusions.

Secondly, while reform efforts prompted by NGSS and the *Framework* often tend to de-emphasize traditionally rote curricula options such as vocabulary and scaffolded inquiry, case study data presented here suggests that these elements can be used to support student reasoning and sense-making. This is not an endorsement of “cookie cutter labs” or an emphasis on “doing school” - i.e. prioritizing “teacher control, curricular coverage, consumption of knowledge, and individualism in learning.” (Winschitl, 2019, page 8). Rather, the strategies inherent in *FACTS* reflect a purposeful inclusion of detailed knowledge and practice in a manner reflective of a “sense-making toolkit”. This is meant to support student engagement with the application of model-based reasoning to authentic local contexts. Teacher feedback and analysis of student performances in the *FACTS* case studies suggest there is value in specificity and structure when preparing students to apply scientific knowledge and practice to real-world contexts. This is in accordance with recommendations from Gee (2005), who argues that proficiency in using science social language depends on utilization of situated instructional approaches in lieu of more traditional verbal emphases. Having students progressively achieve engagement in scaffolded three-dimensional learning using specialist language as means to address problems and design solutions should support greater enablement of productive disciplinary engagement during instruction.

Third, my experiences in collaboratively developing the *FACTS* curriculum raises questions about depth vs. breadth. Arguably, students could have gone into greater depth on a single specific phenomenon as opposed to the broader focus utilized in *FACTS Natural Resources*. Reducing the breadth of the course would potentially reduce the need for the increased level of scaffolding that was eventually adopted in the curriculum. However, a semester-long course like Natural Resources is often the only exposure that most agricultural students will get in a rural high school to applied ecological instruction (as was the case in the pilot study school). Both case study teachers were adamant that the number of units (breadth) should *not* be reduced as they felt that the existing units were all necessary to support students’ reasoning about the range of decisions they may make in agricultural contexts. This suggests that an excessive emphasis on depth in lieu of breadth could potentially of interfere with enabling more informed decision-making to authentic scenarios.

Finally, the case study data presented here prompts questions regarding the assertion that science investigation and engineering design should be the central emphasis of science instruction (National Academies of Sciences, Engineering, and Medicine, 2019). While investigations certainly are prominent in the *FACTS* instructional model, feedback from the instructors suggests that the situated community-based aspects of the course were actually more important for improving informed decision-making among students. This is in alignment of findings and recommendations by Brown, Collins, and Duguid (1989), Lave & Wenger (1991), and Gee (2005) in that traditional classroom science instruction by itself is unlikely to transfer to decisions made in non-classroom contexts. Admittedly an agriscience course has differing objectives than a core science course. However, it might be pertinent to consider that if a key goal of three-dimensional science instruction is to enable more informed decisions in matters of public interest, there are aspects beyond investigations that may require greater prioritization. In the case of *FACTS*, it appears that providing students with the opportunities to use situated social science language to connect pre-existing explanatory models to localized contexts, and to have these models challenged (to a limited extent) in "un-curated" experiences like their Supervised Agricultural Experiences is potentially more impactful than having students develop novel explanatory models that fail to address viewpoints and considerations outside of their classroom instruction.

LIMITATIONS & IMPLICATIONS

The DBR methodology supports efforts to produce and assess an NGSS-aligned agriscience curriculum in a manner reflective of principles inherent in adaptive management. It should be noted that the intent of DBR-based methodologies is not to provide generalizable results, but rather to develop claims about the application of specific theories in particular contexts (Barab & Squire, 2004). As such, I do not attempt to make broad assertions about the capacity of three-dimensional learning (as applied in the *FACTS* case study classrooms) to influence decision-making in agriculture. Rather, I am using this as an opportunity to reflect on insights gained from creating a "proof of concept" for secondary agricultural programs.

While the preliminary results of this DBR study suggest that implementation has been generally successful and well-received by cooperating teachers, it is also likely that a considerable number of agricultural instructors would struggle and/or be skeptical of this particular approach to agriscience instruction. As McKim, Velez, Lambert, & Balschweid (2017) observed, most agriscience instructors lack the background to effectively implement NGSS-aligned instruction (if they are willing to do so). While changes at the national level (such as the AFNR academic standards and professional development opportunities) are ushering in broader acceptance of NGSS-aligned curriculum, significant hurdles remain.

The curricular design strategies described in this paper reflect an attempt to provide the level of scaffolding needed to support implementation among agriscience instructors, but additional forms of support (such as professional development and support networks) are likely needed as well. Even so, it is probable that at least a sizeable fraction of agriscience instructors are likely to be unreceptive to forms of agricultural education that challenge traditional norms and expectations. It should also be noted that agricultural instructors face unique challenges that may affect the adoption of NGSS-aligned curriculum. In particular, agricultural courses are usually offered as electives; if adoption of three-dimensional instruction results in reductions to student enrollment (as occurred initially in this study), an agriscience teacher could lose student enrollment to the extent that it could threaten their employment. As such, there are likely to be considerable struggles if and when this work can be scaled up to broader implementation.

As noted earlier, the work described in this paper is meant to support the initial stages of broader NGSS incorporation in agriscience instruction by developing a "proof of concept" curriculum. It has been my intent to demonstrate that creating and implementing a NGSS-aligned curriculum in secondary agricultural programs is not only feasible but also can result in the adoption of more viable and sustainable agricultural production methods. If the work described in this paper can enable wider recognition of the feasibility and potential of these efforts, it may result in greater buy-in among stakeholders in agricultural education. This could support wider development and adoption of NGSS-aligned agriscience curricula.

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