EFFECTS OF THREE-DIMENSIONAL AGRISCIENCE LEARNING ON STUDENT SENSE-MAKING REGARDING AGROECOLOGICAL PHENOMENA

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ABSTRACT

EFFECTS OF THREE-DIMENSIONAL AGRISCIENCE LEARNING ON STUDENT SENSE-MAKING REGARDING AGROECOLOGICAL PHENOMENA

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Most contemporary reforms in American science education center around ideas of improving student science literacy (Dauer & Forbes, 2016) with the goal of enabling informed engagement on scientific issues (NRC, 2012). This is particularly true for decisions that affect the public interest, including public health, the environment, and the economy (Rudolph & Horibe, 2016). Contemporary research about science learning is synthesized in the *Framework for K-12 Science Education* (NRC, 2012) which advocates for *three-dimensional science learning*. This consists of a seamless combination of disciplinary core ideas, science and engineering practices, and crosscutting concepts (NRC, 2012).

Decisions made by American agriculturalists have a disproportionately large impact on the public interest. Rural landscapes comprise most of nation's land area (Merrill & Leatherby, 2018) and are vital for food production, mitigating climate change, and energy production (Lal *et al.*, 2011). Rural landscapes contain most of the nation's wildlife habitat (NRCS, 2020), much of which is threatened by conversion into farmland (Stubbs, 2014; USDA, 2016). Additionally, conventional agriculture exacerbates stresses to natural systems, threatening food production over the long term (Lengnick, 2015). Three-dimensional agriscience instruction could be useful for preparing agriculture students to improve food production for its long-term viability and ecological sustainability. The agricultural education instructional model may provide opportunities to provide three-dimensional science learning that is more responsive to students' individual identities and experiences.

This dissertation study reports on the results of a design-based research (DBR) project involving how a NGSS-aligned agro-ecology course prepared secondary students in three focus groups to explain and manage ecosystems in rural agricultural landscapes. The intent was to determine students' changing capacities to define problems that can affect agriculture due to reductions to biodiversity, ecosystem services, carrying capacity, and resilience. Students were prompted to provide three-dimensional performances in focus group interviews to demonstrate their capacities for reasoning and decision-making about agro-ecological phenomena.

In addition to the sophistication of their responses, I analyzed student performances using three criteria: *framing*: the perspectives from which students were perceiving and interpreting the interview questions; *transfer*: students' capacities to connect ideas and practices from the curriculum to authentic contexts; and *discourse*: how students engaged in opportunities to express their ideas and build on one another's responses.

While students in all three focus groups learned through the same curriculum, differences in implementation resulted in different outcomes among these students. My findings allude to the challenges inherent in enabling more informed decision-making through three-dimensional science learning, which may necessitate considerations beyond the classroom itself. Student performances appear to be at least partly determined by opportunities to reason about problems from multiple perspectives, to gain experience in applying classroom knowledge and practice to authentic contexts, and to collaborate to deepen their comprehension and develop more sophisticated responses.

This dissertation is dedicated to all educators and researchers who
strive to create a more productive, peaceful, and sustainable future.

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In addition, my committee members played valuable and instrumental roles as my dissertation evolved. Dr. Aaron McKim's detailed feedback not only improved the quality of my writing but pushed me to think more deeply about the intricacies and nuance of school-based agricultural education. His guidance was instrumental in aligning my work to the norms of this field. Dr. Angela Calabrese-Barton's work was central to my understanding of community-based learning and the role that students' identities and funds of knowledge serve in achieving educational outcomes. Her feedback pushed me to think about equity and inclusivity in science education much more deeply than I ever imagined. Finally, Dr. Adam Zwickle's vast background in decision science and risk analysis provided key opportunities to link my educational research to the kinds of decisions made outside of schools in a systematic and rigorous fashion.

I would also like to acknowledge my case study teachers without whom this dissertation could not have happened. Mrs. E and Mrs. B not only provided valuable opportunities to collect data in their classrooms (usually at the expense of their time and energy) but also proved to be valuable partners in educational research. Their insights, modifications, and suggestions vastly improved my curriculum development and subsequent data collection and analysis, and I am exceptionally grateful for their contributions and expertise in the field.

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INTRODUCTION

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Most contemporary reforms in American science education center around ideas of improving student science literacy (Dauer & Forbes, 2016). A key goal of these efforts is to provide students with the habits of mind and patterns of practice that enable them to “understand, judge, and use science in productive and scientifically aligned ways in his or her life” (Covitt, Dauer, & Anderson, 2017, p. 59). In addition to fostering an appreciation for science, most of science literacy-oriented reforms in American education are designed with the goal of improving public engagement on scientific issues that arise in personal and professional settings (NRC, 2012). This is particularly true for instances in which scientific literacy is necessary to guide decisions that will affect the public interest, including areas such as public health, the environment, and the economy (Rudolph & Horibe, 2016).

Overview of Three-Dimensional Science Learning

Much of the contemporary research literature about science learning is synthesized in National Research Council’s *Framework for K-12 Science Education* (2012). The *Framework* serves as the research basis for most state science standards, including the *Next Generation Science Standards* (NGSS Lead States, 2013). The *Framework* establishes a progressive vision for science education and advocates for *three-dimensional science learning*, or a seamless combination of disciplinary core ideas, science and engineering practices, and crosscutting concepts (NRC, 2012). The *Framework* describes these three dimensions in the following manner:

Science and Engineering Practices. Rather than merely simulating how scientists and engineers conduct their work, the Framework stipulates that students themselves should be engaged in the practices of scientists and engineers. The specific use of the term “practice” reflects the need for both knowledge and skill in scientific pursuits. Examples include analyzing data, evidence-based argumentation, developing explanatory models, and evaluating information.

Crosscutting Concepts. Some key concepts shape our reasoning in many branches of science and engineering. These include identifying patterns, establishing cause and effect, and recognizing the conservation of energy and matter. These provide constraints to reasoning that guide scientists and engineers towards more valid conclusions and more viable solutions.

Disciplinary Core Ideas. While fact memorization has minimal utility in modern society, some understanding of scientific content is necessary to prepare students to make sense of the world throughout their lives. The Disciplinary Core Ideas reflect a very limited set of concepts with broad explanatory power that support productive reasoning and problem-solving.

The Framework’s vision for science education reflects a shift beyond just investigating the natural world to enabling students to accurately reason about phenomena and develop viable solutions. One hallmark of three-dimensional learning is that more emphasis is placed on “figuring out” rather than “learning about”. This means that students engage in sense-making in which they must use both knowledge and practice to explain phenomena and design solutions (Schwarz *et al.*, 2017).

Science Literacy and Decision-Making in Agriculture

Decisions made by American agriculturalists have a disproportionately large impact on the public interest. While fewer than 2% of Americans are employed as full-time farmers (BLS, 2019), over 72% of the land area of the contiguous United States is used for agriculture and private forestry (Merrill & Leatherby, 2018). Rural areas provide most of the natural resources needed for increasing food and energy production; additionally, rural agricultural land may provide critical opportunities for the mitigation of climate change through alternative energy production and carbon sequestration (Lal *et al*., 2011). Furthermore, while agricultural land provides much of the nation's wildlife habitat (NRCS, 2020), economic pressures have increased the rate at which farmers are converting restored habitat areas back into food production (Stubbs, 2014). Between 2007 and 2016, almost 13 million acres of restored on-farm habitat was converted back into agricultural use (USDA, 2016). More broadly, modern agricultural production practices generally have unsustainably high consumption rates of natural resources and tend to exacerbate stresses to natural systems; this threatens the capacity to maintain existing levels of agricultural production over the long term (Lengnick, 2015).

Impact of Agricultural Education

While urban and suburban schools rely primarily on science teachers to teach sustainability-related goals, agricultural educators play a key role for sustainability instruction in many rural schools. The insights provided by the NRC *Framework* and NGSS, especially regarding the *three-dimensional engagement* in science are underutilized in agriscience education in comparison to core science courses. Three-dimensional agriscience instruction could be useful for enabling students to develop the habits of mind and patterns of practice needed to critique existing options in food production for their long-term viability and ecological sustainability.

Most secondary school-based 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) situated 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 may provide both unique affordances and challenges regarding achieving student outcomes related to three-dimensional science learning, but there appears to be few if any investigations into these considerations.

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 implementing 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 way 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. Among the agricultural instructors who express motivation to incorporate science into their instruction, most lack the preparation to do so effectively (McKim, Velez, Lambert, & Balschweid, 2017).

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.

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 and agricultural educators perceived threats to future food production (Kohn & Anderson, in review). 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 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.

Limitations of Classroom Science Learning

In addition to the challenges described above, the norms and environments of classrooms can serve as obstacles to enabling more informed decision-making. Classroom environments rarely resemble the kinds of conditions in which students will make decisions as adults. Furthermore, factors outside of the classroom can matter as much as the way science instruction is implemented within the classroom.

The work of Paul Gee's (2005) alludes to this when he argues that students' lived experiences, identities, and interactions are key to "higher levels of school success" (p. 19) in science learning. Gee argues that learning science content alone is not sufficient to prepare students for their adult roles in modern societies. For science learning to adequately prepare students for these obligations, it must address and respond to students' individual identities, their experiences as learners, and their capacities to engage in productive discourse.

Role of Identity & Perspective. According to Gee, learning science is "integrally involved with identities and social practices" (p. 19) in a manner similar to acquiring a new *social language*. This language entails not only a new way to describe the world, but also a new means for reasoning and responding to it. For students to succeed at this, they must "participate in another identity" (p. 23) beyond that which they have in their own homes. Gee argues that their willingness to adopt this identity depends largely on whether they can see relevance in the subject matter for their own lives. In other words, for students to successfully become "bilingual" in science, the relevance to their prior experiences and/or to particular social contexts must be obvious and explicit.

Gee (2005, p. 23) specifically addresses this concept when he claims: "One does not know what a social language means in any sense useful for action unless one can situate the meanings of the social language's words and phrases in terms of embodied experiences." What students learn in science classrooms will lack usefulness for enabling informed decisions unless it is explicitly linked to the real-world systems in which those decisions will occur.

Role of Experiences & Engagement. Gee (2005, p. 25) argues that how students understand scientific concepts is "rooted in embodied experience" and that "one has to 'see' the meaning as a pattern extracted from the concrete data of experience." In other words, for students to meaningfully comprehend a phenomenon, it is not enough for them to gain indirect experience through verbal meanings. As Gee argues (p. 25), while verbal meanings "can facilitate passing certain sorts of tests, [they] are of limited value when language has to put to use within activities." Whether students can apply knowledge and practice to authentic contexts depends on the extent to which those contexts are explicitly incorporated into their classroom learning experiences.

Role of Discourse & Dialogue. Gee argues that students need to have opportunities to express their ideas and build on one another's responses to gain sufficient preparation to use ideas and practices from their science courses in real-world settings. Inherent in this are two key ideas: 1) that students need a level of fluency to be able to effectively express their ideas in a manner that accurately and fully encapsulates phenomena; and 2) that they can listen and respond to their peers in a manner that results in more precise and more meaningful descriptions.

Gee (2005, p. 24) addresses the first component when he describes the differences between verbal and situated language. He argues:

> Social languages can be understood in two different ways, either as largely verbal or as situated … Words and phrases in use in any social language, including lifeworld social languages, have not only relatively general meanings (which basically define their meaning potential), but situated meanings as well. Words and phrases are associated with different situated meanings in different contexts, in different social languages, and in different Discourses.

As such, it is not enough for students to gain familiarity with terms from the course; for their education to be useful for action, students need to be able to contextualize language from the course as it specifically pertains to phenomena as they are embodied in authentic contexts. In the words of Gee: “If one cannot situate the meaning of a word or phrase, then one has only a verbal or definitional meaning for the word or phrase.”

Secondly, students depend on opportunities through group discourse to gain fluency in applying ideas and practices from the course to real-world systems. As Gee (p. 28) argues, “social interaction and dialogue of a certain sort are also crucial to the acquisition of any social language whatsoever.” He goes on to recommend that students should be provided with regular opportunities for…

> “…discussions where children are asked to take longer turns, expand their language, and make clear their reasoning and its connections to what others have said. In such “mono-dialogical discussions” students need, also, to be overtly scaffolded in how they use and think about scientific social languages, interpretations, and arguments.”

According to Gee, students cannot gain a sufficient level of fluency in scientific ideas and language through individualized participation. Successful outcomes in science classrooms depend on ongoing opportunities for scaffolded interpersonal dialogue.

Overview of Dissertation

My dissertation study is part of a larger project (funded by an NSF graduate fellowship) for which my goal is to design a ‘proof of concept’ curriculum that both aligns to the AFNR academic standards as well as NGSS in a manner that feasibly enables three-dimensional science learning in agriscience classrooms. The overarching objective of this curriculum is to enable more informed and more sustainable decision-making in regard to rural agricultural land use as a result of three-dimensional science learning.

This dissertation study specifically reports on the results of a design-based research (DBR) project involving how a NGSS-aligned agro-ecology course prepared secondary students in three separate focus groups to explain and manage ecosystems located in non-production segments of rural agricultural landscapes. This work addresses the ramifications of potential management decisions on biodiversity--habitat carrying capacity for different species—as well as associated ecosystem services. These management decisions include 1) spatial considerations such as the size and connectedness of habitats, and 2) change over time, such as how different kinds of disturbances (e.g., natural disasters vs. human development) affect habitat continuity. Through curricular emphases on system models and cause and effect, students are guided in using adaptive management strategies to identify tradeoffs regarding potential land management decisions.

RESEARCH QUESTIONS

This was a bounded multi-site case study (Merriam, 2009) involving the adoption of an experimental sustainable agriculture curriculum by secondary agriscience programs in two rural schools in different states. This study primarily investigated how students in three focus groups reasoned about land use in rural agricultural areas as a result of three-dimensional ecological learning opportunities in a NGSS-aligned agriscience course. The intent was to determine students' capacities to define problems that can affect agriculture due to reductions to biodiversity, ecosystem services, carrying capacity, and resilience. I assessed changes to students' capacities to address this target performance through multiple focus group interviews. Through these interviews, students were prompted to provide three-dimensional performances to demonstrate their capacities for reasoning and decision-making about agro-ecological phenomena.

This study explores the following research questions:

1. **RQ1: How did participation in the course change students' ability to reason about food production and land use in terms of…**
    a. Factors that emphasize demand (e.g., population growth and its impact on consumption, associated technologies, and their impact on local and global ecosystems).
    b. Supply side factors associated with patterns of land use in rural landscapes (e.g., managed cropland vs. adjacent habitats) including:
        1. Strategies for managing crop production;
        2. Characteristics of less managed lands (e.g., ecosystem services provided by sufficient levels of biodiversity); and

3. Interactions between cropland and less managed lands; and…

c. Mechanisms through which these factors affected crop productivity and/or system sustainability.

2. **RQ2: How did the students' classroom experiences differ with respect to framing of content, opportunities for transfer, and discourse, and what ramifications did these differences have on student performances as described in RQ1?**

CONTEXT & METHODS

This project emerged from a multi-year design-based research study that aimed to develop a NGSS-aligned agriscience curriculum and investigate its effectiveness for enabling more informed decision-making among high school agricultural students. Design-based research (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).

This work began in 2016 through a Graduate Research Fellowship from the National Science Foundation. The resulting 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 (www.factsnsf.org) is to enable more informed practice among agricultural students, particularly regarding increasing the adoption of more sustainable knowledge and practice for decisions made in rural agricultural contexts. This project is an offshoot of 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).

Overview of the FACTS Curriculum

I designed the FACTS Natural Resources curriculum to engage students in three-dimensional reasoning about the interactions between ecological factors (e.g., biodiversity, ecosystem services, resilience, carrying capacity, etc.) and human activity like agriculture. This curriculum addresses both demand factors (e.g., disturbances from excess atmospheric CO_2 from fossil fuel combustion) as well as supply side factors (e.g., eutrophication because of nutrient runoff from crop production). The curriculum was designed to provide a basis for deeper reasoning about mechanisms that affect system productivity and sustainability. This curriculum more frequently addresses demand factors and characteristics of less managed lands in rural landscapes; it places less emphasis on specific strategies for crop production as this is addressed in much greater detail during the subsequent FACTS Horticulture and Agronomy course.

Curriculum Sections

The FACTS Natural Resources curriculum is divided into weekly units. These units are grouped into three sections. The first section (Atoms to Ecosystems) was designed to enable students to explore ecosystem function in less managed lands. Students begin by investigating changes in matter and energy at atomic and cellular scales (e.g., photosynthesis, respiration, and biosynthesis). Students then investigate how natural selection as well as the availability of biomass determine levels of biodiversity, and how changes in biodiversity affects ecosystem function, resilience, and carrying capacity.

In the next section (Causes of Extinction), the emphasis shifts to factors that emphasize demand. Students determine how the four leading causes of reduced biodiversity (habitat loss, invasive species, pollution, and overharvesting) relate the impact of human activity on local and global ecosystems. This provides explanatory models for students to reason about local interactions between human managed ecosystems (like cropland) and adjacent habitats. Students conclude this section by assessing the threats impacting a habitat near their school and designing solutions to mitigate these threats.

The final section (Sustainable Societies) provides opportunities to analyze how supply and demand factors relate to losses of biodiversity at both global and local scales. Students designs campaigns to assess a particular threat and develop a strategy that balances tradeoffs between human needs and impacts on biodiversity and ecosystem function.

Weekly Unit Structure

Most FACTS units are designed to follow a five-day unit structure. On Day 1, students engage in reasoning and sense-making about data from a relevant case study through group and whole-class discourse. On Day 2, students compare their initial ideas to existing explanatory models, 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 situated in local agricultural and environmental contexts. On Day 4, students are guided through a review and assessment. Students conclude the unit on Day 5 with community and career connection activities involving personal and/or localized contexts.

Situated Learning

As an agriscience course, the FACTS Natural Resources curriculum was designed to align to the Three Circle Model of Agricultural Education. This instructional model stipulates that school-based agricultural education should consist of an overlapping combination of classroom learning, supervised agricultural experiences (or SAEs), and personal and leadership development. In particular, the course was designed to integrate student community-based learning (primarily via their SAEs) into classroom instruction. This was intended to provide more personal engagement with phenomena related to the target performance while also grounding classroom discourse in local authentic contexts. The default expectation is that students gain at least 15 hours of community-based experiences in a field related to the course and/or their future careers (although teachers have the option to change this as they see fit).

The curriculum also embeds opportunities for personal engagement with phenomena through investigations. The curriculum regularly prompts teachers to situate investigations in local habitats surrounding the school when feasible (classroom-based alternatives are provided when this option is not feasible). The curriculum also prompts teachers to support classroom discourse that melds students' lived experiences and funds of knowledge with curricular content.

Participants

I used posts on my own curricular websites as well as the National Association of Agricultural Educator's *Communities of Practice* curricular-sharing website to recruit teachers and their classrooms for this study. These posts included a link for interested teachers to provide their contact information as well as some background information (such as the number of years taught, licensure, etc.). See Appendix A.

Prior to the start of the study, I emailed all teachers who had expressed interest to solicit participation and provide details as to what this involvement would entail. Based on experience in teaching (3+ years), licensure (agriculture education and possibly science certification), and willingness to fully implement the curriculum, I selected two teachers' agriculture programs as case study data sources.

The findings of this paper are based on performances from focus students and their instructors in three case study classrooms. General information about each group is summarized in the table below. The names of the schools and instructors are pseudonyms. Focus group participants were selected by their instructor at the start of the school year and reflected a range of abilities and backgrounds when feasible. Specific details about each teacher, their schools, and surrounding community are provided in the Results section.

Table 1 – Summary of case study schools and participants.

Group	Year	School	Location	Instructor	Students
Group A	2019-2020	Lanesville	Rural area of a midwestern state	Mrs. E	Two males Two females
Group B	2019-2020	Shoehaven	Rural area of a northeastern state	Mrs. B	Four females
Group C	2020-2021	Shoehaven	Rural area of a northeastern state	Mrs. B	One Male Two Females

Data Collection and Analysis

My conclusions primarily emerged from qualitative interviews with focus students and their instructors in the three case studies. In addition, I used classroom observations and focus student assessment responses to develop my findings.

Student Focus Group Interviews

Data Collection. I conducted monthly interviews over the course of the semester with each student focus group. The interview protocol for this work can be found in Appendix B. The first interviews were scheduled to occur within a couple of weeks of the start of the school year to provide adequate time to distribute and collect consent forms and enable the teacher to recruit potential focus students from a range of backgrounds. The final interview was scheduled to occur within a week of their final exam for the course. Students were compensated with gift cards from major retailers (e.g., Amazon or Apple) and were informed that their participation was voluntary and would not affect their grades. The focus group interviews were semi-structured; while there was an interview protocol, students were given flexibility to deviate from these questions.

Each interview began with the same set of questions focusing on how students perceived threats to food production and what solutions they recommended. Additional blocks of questions were added to the final interview of the 2019-2020 case studies and to all interviews during the 2020-2021 school year. Students were first asked to compare insect and vertebrate extinction data, infer how this could affect ecosystem function and ecosystem services, and how this might affect and or be affected by human activity. Students then evaluated competing claims about how farmers manage the non-producing portions of their farms. They concluded with questions that prompted them to design more sustainable production options for a conventional farm that balanced production with biodiversity and ecosystem function. If time remained, students were asked to provide their overall perceptions of the course, to describe anything that was particularly impactful, and to describe how the course affected decisions they made outside of the classroom (if at all).

Data Analysis. All focus group interviews were recorded. These recordings were transcribed using paid online services (*Temi* and *GoTranscript*). I then analyzed each student interview transcript using two different coding frameworks. These are summarized in the following sections.

Initial Coding Framework Development. I initially analyzed focus group interview transcripts for their sophistication and capacity to achieve the target interview performance. To do so, I developed a coding framework using methods like those utilized in learning progression research. Rather than focus on students' understanding of specific concepts, this approach to education research looks at how students approach a broad set of ideas and concepts (Parker *et al.,* 2015). In particular, learning progressions provide a valuable means to evaluate how students' thinking changes over time in response to educational interventions (Wyner & Doherty, 2017). Due to the narrow scope of my work, the learning progressions I developed were primarily used as coding frameworks for my own data and do not provide a broad representative account of student reasoning about these topics.

My development of a coding framework was similar to the processes described for learning progressions by Jin and Anderson (2012). I first divided interview transcripts into excerpts using the computer coding program *Dedoose*. For this paper, an excerpt consisted of students' responses after the interviewer's question until the interviewer started a new question or a follow-up question. I then inductively identified patterns across student responses based on their type of reasoning (e.g., good/bad heuristics, simple correlation, complex correlation, or causal mechanisms) for each excerpt and each question and assigned codes based on initial sophistication as well as question type. This process enabled me to identify general indicators to sort responses and iteratively refine the coding application. In doing so, I confirmed that my inter-coder and intra-coder reliability met recommendations from Creswell (2014) and Tomita *et al,* (2009) to ensure sufficient agreement. The resulting coding framework can be found in Appendix C.

Transfer-Framing-Discourse Framework. The results from this coding framework provided me with a general basis to compare the changes in sophistication between the initial and final interviews for each focus group. However, the intent of the focus group interview questions was to assess changes to students' capacities to define problems that affect authentic agricultural contexts due to changes to biodiversity and other ecological factors. Achievement of this target performance depends on factors beyond sufficient comprehension of content. As such, I was also interested in students' capacities to frame the interview questions from consumption, production, and stewardship perspectives, to transfer ideas and practices from the course to authentic contexts in the interview questions, and to collaboratively listen and respond to each other's ideas to achieve more sophisticated responses.

The use of framing, transfer, and discourse to characterize student interview performances initially emerged from comments that the case study teachers made during their interviews. Both teachers identified opportunities for personal engagement with phenomena (e.g., outdoor investigations situated in local habitats) and group work as the most important aspects of the curriculum for enabling more informed decision-making. Based on this feedback, I re-analyzed differences between student performances as well as differences in classroom implementation. Through this iterative process, I was able to identify framing, transfer, and discourse as key considerations that affected whether students achieved the interview target performance.

These conclusions are also supported by other research. As mentioned in the introduction, Gee (2005, p. 19) argues that identity, experience, and language are key to "higher levels of school success" in science learning. Gee argues that for science learning to adequately prepare students for their roles as adults, it must address and respond to students' individual identities, their experiences, and their capacities to engage in productive discourse. In the following paragraphs, I will provide a more precise definition of each aspect of this framework using insights from cited literature and summarize how I analyzed student responses based on this criteria.

Analysis of Framing. Scherr and Hammer (2009, p. 149) draw from traditions in anthropology and linguistics to define *framing* as the sense of "What is going on here?" They define *epistemological framing* as the "sense of what is taking place with respect to knowledge" (p. 149). They argue that student success depends not only on knowing what knowledge and experience are needed for completing assignments, but also in identifying what students should expect of themselves, their peers, and their instructor. For example, whether students view an assignment as simply a worksheet to completed or as an opportunity for intrinsically motivated sensemaking shapes what knowledge is accessed and how they respond.

Russ *et al.* (2012) applied this concept to clinical interviews in educational research. They define framing as the “set of expectations about how to behave in [a] situation,” or how to meaningfully and productively engage with others (p. 576). They determined that how students perceived their expected role in an interview affected their capacity to respond to questions. As a result, student performances did not always align to their level of comprehension. Kapon (2017) expands on this to define framing as the manner in which contextual and interactional constraints influence how individuals develop explanations. She argues that how students determine if an explanation is appropriate depends not only on their perceived roles but also the elements of knowledge that are referenced by the task and the mechanism of explanation needed to provide a successful response.

For my work, I draw from each of these perspectives. I define framing as the perspectives from which students perceive and interpret tasks such as interview questions or their classroom performances. This definition is most similar to Kapon’s (2017) in that it addresses what constitutes an optimal performance as well as identifying the elements of knowledge needed for successful performances. In my work, these elements can include both production and consumption considerations as well as different aspects of sustainability (ecological, economic, and social).

For example, a student who only considered the ramifications from consumption of food (e.g., mileage to the grocery store, amount of plastic packaging, etc.) without regard to production decisions would have been less capable of making fully informed evaluations that support system-level sustainability. In contrast, a student who was able to consider decisions at each stage of production and consumption from ecological, social, and economic viewpoints would have been more capable of making more informed choices. In this sense, framing could be more generally defined as whether students were capable of analyzing a system from all relevant and meaningful perspectives.

To analyze student interviews in terms of framing, I categorized their responses based on whether their responses reflected the perspectives of consumers, producers of food, environmental stewards, or a combination of these perspectives. For example, if students identified food waste as a primary threat to food security, they would primarily perceive the interview question from a consumer's perspective as this reflects the kinds of choices primarily made by consumers. Conversely, if they identified nutrient runoff from excess tillage as a key threat, they were doing so primarily from a production and stewardship perspective. Additionally, students' positionality could be partially determined by their use of pronouns. For example, the phrase "they need to produce more food" alludes to a consumer perspective, whereas a production perspective would be more likely to be framed as "we need to produce more food."

Analysis of Transfer. The traditional and dominant view of *transfer* was "whether people can apply something they have learned to a new problem or situation" (Bransford and Schwartz, 1999, p. 67). Thorndike & Woodworth (1901) were particularly notable advocates for this perspective, challenging early assumptions about the impact of learning environments that provided generalized education in lieu of rote training for particular tasks. They concluded that successful mastery of specific content does not necessarily transfer to new and different situations.

Bransford and Schwartz (1999) proposed a different conceptualization of transfer through what they called *preparation for future learning* (PFL). This can be understood as "the capacity to learn new information, to use resources effectively and innovatively, and to invent new strategies for learning and problem solving in practice" (Mylopoulos *et al.,* 2015, p. 116). This perspective emphasizes student preparation to continue to learn and respond to challenges in knowledge-rich environments. *Transfer* in this context can be measured by the "speed and/or quality of new learning" (p. 68).

In my work, I address the concept of transfer from both perspectives. I define transfer as students' capacities to connect ideas and practices from one context to another as a means to develop novel explanations and/or solutions for real-world considerations. This requires students to identify relevant connections between the ideas and practices they previously encountered and phenomena in real-world systems. It also requires students to successfully adapt to conditions for which they were not explicitly prepared. In this study's interviews, students needed to be able to identify how ecological knowledge and practice related to food production and respond to tasks that were not explicitly part of their classroom training. Students with sufficient capacities for transfer were capable of identifying relevant ideas and practices needed to respond to interview tasks in an adaptive fashion.

To assess transfer, I coded interview excerpts based on whether student responses primarily addressed specific curricular content from the class, experiences outside of the curriculum that related to their classroom learning, or experiences unrelated to their classroom learning. I also determined the accuracy and fluency in which students used terms from the course. For example, if students used disciplinary terms inaccurately or vaguely, this suggested a lower capacity for transfer than if students used a term precisely without assistance or prompting.

Analysis of Discourse. The term *discourse* generally refers to how groups of individuals communicate (Cazden, 1986). For my work, I draw from research in mathematics education on developing classroom discourse communities. In particular, Sherin (2002) describes *classroom discourse* as having key properties that distinguish it from other forms of discourse, including a) students voice and explain their ideas; b) students respond to the ideas of their classmates; and c) teachers facilitate conversations to elicit students' ideas.

These properties are increasingly recognized as essential for effective science instruction. In particular, Michaels and O'Connor (2012) argue that academically productive classroom discourse emerges when students are able to consider multiple perspectives, identify and address evidence for these positions, and identify connections among all students' ideas. Furthermore, the use of a variety of formats (whole-class discussion, group work, and partner talk) encourages more engaging and equitable discussion. These authors suggest that productive classroom discourse encourages deeper evidence-based reasoning that enables more robust learning and comprehension among students. Similarly, Carpenter *et al.* (2020) argue that classroom discourse provides opportunities for students to clarify their thinking and reasoning about phenomena in a manner that results in more productive sensemaking.

For this paper, I define discourse as how students engaged in opportunities to express their ideas and build on one another's responses. While this primarily pertains to their interview performances, these performances are assumed to be influenced by their opportunities for productive classroom discourse. My definition of discourse contains key elements, including whether a) students voiced their ideas during the interviews; b) students listened to their peer's responses and engaged in dialogue about their ideas in a manner supported by evidence, reasoning, and system models; and c) these exchanges resulted in more sophisticated and more precise responses.

An important indicator of students' capacities for discourse was the extent to which a student's idea or statement was addressed by other students in that interview. Students with a strong capacity for collaborative discourse generally acknowledged ideas from their peers, responded to these ideas by either reinforcing or challenging them, and used this collaborative dialogue to enable a more sophisticated response. Their interviews were characterized by "interview-student X-student Y-student…" patterns of dialogue. For example, in one interview, a student argued that ecosystem 'strength' was an important consideration; another student immediately clarified that they meant 'resilience', which enabled the group to provide a more precise description of their ideas. These interviews were also characterized by more rapid exchanges of ideas, competition to contribute, completion of other student's sentences, and brief debates about ideas.

Conversely, students with a limited capacity for collaborative discourse rarely responded to ideas from their peers. Their interviews were characterized by "interviewer-student X-interviewer-student Y" patterns of dialogue. For instance, a student might provide their response to a question, followed by additional prompting by the interviewer, followed by a different response from a different student. These interviews were also characterized by long pauses, limited debate or follow-up among students, and more frequent use of "I don't know" or "We're good" kinds of statements.

Teacher Interviews

Data Collection. I interviewed case study teachers for each focus group two to three times per semester. I scheduled interviews to occur at the mid-point and end of the semester; an additional interview was scheduled in between these if feasible. Teachers were compensated with gift cards from major retailers (e.g., Amazon or Apple). These interviews were also semi-structured; while there was an interview protocol, teachers were given flexibility to deviate from these questions. These interviews provided opportunities to document how the curriculum was implemented differently. This was an important factor for explaining differences that occurred between focus group performances during their interviews. This also provided an opportunity to gain insights regarding the extent to which classroom performance correlated with interview performances among the focus students.

The teacher interview protocol is included in Appendix D. Teachers were first asked a general "How's it going?" introductory question to open dialogue and allow them to convey the ideas that are most on their mind at that moment. I then asked teachers to reflect on how they enabled three-dimensional performances in their classrooms through opportunities such as discussion, group work, individual work, etc. This was followed by a question in which teachers were asked to reflect on which aspects of their teaching seemed to have had the most impact on improving informed decision-making among students. In the fourth question, teachers were asked to describe the changes they have made in curriculum implementation as well as the reasons for these changes.

Teachers were then asked to provide their observations about how students were changing regarding their sense-making and reasoning, and whether factors outside of the curriculum might have influenced these outcomes. To conclude the interview, I asked teachers if there is anything else they would like to share to provide a final opportunity to record their input and observations.

Data Analysis. Because the interview questions directly pertained to the research questions (RQ2), much of the analysis was self-evident based on how teachers responded to the questions. For example, each teacher was asked to summarize how they implemented the course on a day-by-day basis in addition to descriptions of how they structured group discourse, investigations, and engagement with phenomena. Additionally, I noted where teachers differed from the claims and observations of students in their respective interview responses. In prior years it has been evident that teachers sometimes over-estimated the extent to which students improved regarding their knowledge and practice. Similarly, what students find valuable about a particular aspect of their instruction often differs from the perceptions of their instructor.

Student Classwork and Assessments

Data Collection. I asked each case study teacher to make copies of classwork and assessments for each focus student. Due to COVID-19, the hard copies of these items were lost. The only items that I was able to collect were digital copies of the Group B and C focus student responses to the midterm exam (Group A's case study teacher provided me with average scores for each question but not the responses themselves).

Data Analysis. I evaluated student responses to three-dimensional questions using the initial framework that I used to code the student interview responses. This primarily entailed assessing the accuracy of their writing as well as categorizing the type of reasoning used to address the question (e.g., good/bad heuristics, simple correlation, complex correlation, or causal mechanisms) to determine the sophistication of the response. I also evaluated the extent to which students could accurately utilize disciplinary language and system models in their responses.

Changes from the Proposal

Due to COVID-19, I was forced to deviate from my original dissertation proposal in several ways. First, I had originally proposed to compare two case study groups during the 2020-2021 school year. My data collection during the 2019-2020 school year was primarily meant as a pilot phase for establishing my research protocols. However, my Midwestern case study teacher was told by her administrators to withdraw from the study in August of 2020 due to COVID-19. As such, I opted to use the case study data I had from the 2019-2020 school year out of necessity.

Second, I had proposed to use pre- and post-assessments, midterm exam responses, and classroom observations as sources of data. While I do have pre- and post-assessment data from 2019-2020, I only have this data for one case study site (the second case study's data was incomplete). Furthermore, because I did not assign unique anonymous identifiers for each student, I was unable to determine if changes between the quantitative data from pre- and post-assessment were statistically significant. Furthermore, without similar data from the remaining case studies, this option had limited value for addressing my research questions.

I was able to complete weekly classroom observations during the 2020-2021 school year. However, this option was not feasible during the 2019-2021 school year due to extensive obligations for time in my doctoral program. I had attempted to have teachers capture audio recordings of their instructions for selected units using devices that I provided by mail. However, neither teacher was successful in recording this data despite multiple attempts throughout the semester. Similarly, while teachers had collected copies of student work during the 2019-2020 school year, these items were lost during classroom cleanings after in-person instruction was cancelled in March 2020.

Finally, I did receive midterm exam responses for Groups B and C from their case study teacher. However, the case study teacher for Group A only provided me with the average scores for each question. I had followed up with a request for the written responses for these focus students, but the case study teacher was unable to provide me with this data. I have included a brief analysis of the data I do have. However, given the limitations I have described, this was included primarily for the purpose of triangulation.

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 regarding 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.

RESULTS

I collected my data from three focus groups enrolled in the agricultural education programs of two rural schools. For each of the three focus groups, my intent was to use their interview responses to evaluate their progress towards a key target performance. Furthermore, I wanted to understand how differences in the implementation of the curriculum as well as their personal backgrounds and out-of-class experiences affected their performances in the interviews. While all students were interviewed at similar points while they were enrolled in the course, each group of students provided differing performances that reflected variances in their respective learning environments and individual experiences.

I will begin by providing analyses of the similarities and differences between the focus group participants and their initial interviews, with an emphasis on the resources and heuristics they used and the challenges they initially faced in achieving the key target performance. I will follow this with classroom narratives that demonstrate how factors such as students' backgrounds, teacher implementation, and circumstances inside and outside the school constrained or enabled students' capacity to achieve the target performances. Finally, I will conclude this section by describing the progress each group of focus students made toward achieving the key target performance.

Focus Group Participants & Initial Performances

Each focus group took part in 3-4 interviews throughout the semester they were enrolled in the course using the FACTS curriculum. The initial interview occurred before focus students started the Biodiversity and Ecosystems unit (Week 3). I began all interviews with the following:

> By 2050 we need to produce 70% more food to accommodate for projected increases in demand. However, there are some concerns about sustaining our current level of food production, let alone expanding it. What do you see as being the greatest threats between now and 2050?

If it did not come up, I then asked students to address how changes to biodiversity and ecosystem function might affect food production. I also asked students to provide solutions that would address their identified threats.

The intent of these questions was to determine students' capacities to define problems that can affect agriculture and other forms of human activity due to reductions to biodiversity, ecosystem services, carrying capacity, and resilience. Successful achievement of this key target performance depended on students' abilities to 1) identify patterns between biodiversity, ecosystem services, carrying capacity, resilience, and human activity; 2) use evidence from examples to support their arguments; and 3) define the problems and solutions using causal mechanisms and system models. To bridge the interview questions and these performances, students needed to be able to:

a. Consider factors that emphasize demand (e.g., population growth and its impact on consumption, associated technologies, and their impact on local and global ecosystems).
b. Address supply side factors associated with patterns of land use in rural landscapes (e.g., managed cropland vs. adjacent habitats) including:
    1. Strategies for managing crop production;
    2. Characteristics of less managed lands (e.g., ecosystem services provided by sufficient levels of biodiversity); and
    3. Interactions between cropland and less managed lands, and

c. Explain the mechanisms through which these factors affected crop productivity and/or system sustainability.

In the following sections, I will begin by providing a brief description of the strategies each focus group used to respond to the introductory questions in their initial interview. In each case, I will provide a summary of how their responses align to the sequence above (a, b1-3, c). I will also summarize student performances in terms of three key factors: *framing*: the perspectives from which students perceived and interpreted the interview questions; *transfer*: students' capacities to connect ideas and practices from one context to another as a means to develop novel explanations and/or solutions for real-world considerations; and *discourse*: how students responded to opportunities to express their ideas and build on one another's ideas. I will conclude this section with a comparison of the initial similarities and differences across the three focus groups.

Group A – Group Discourse and Personal Engagement with Limited Perspectives

Group A (Year 1, Lanesville) consisted of four students with a range of academic abilities. This group consisted of two males and two females. All of the students in Group A were described by the instructor as "lake kids," whose parents worked in a nearby city and who generally lacked direct connections to production agriculture: "It just goes over their heads when it comes to agriculture." The instructor observed that the focus students felt a much stronger connection to the aspects of the course that pertained to outdoor recreation and environmental stewardship (b2). Given their backgrounds, students in Group A framed their responses to the interview questions more from the perspectives of consumers (a) rather than from that of agricultural production (b1, b3, c).

Focus on demand for food rather than supply. Given their first interview occurred shortly after the semester began, Group A identified threats and proposed solutions in a manner that primarily reflected their backgrounds and personal experiences. Students in this group initially framed their responses to the first question from a demand perspective, focusing on population growth as a key threat to sufficient food production. For example, students in Group A argued that "people are definitely having kids at a young age now than they did…so we're gonna have to feed a lot more people now." They also argued that in addition to "more mouths to feed," population growth also had other ramifications for global systems and rural ecosystems: "It also makes it more challenging to feed those mouths because of the side effects, if you will, of a growing population. There's more emissions and there's more pollution." This focus on systems other than rural landscapes was also evident in some of their proposed solutions, including lab-grown meat, improvements to education, and finding more "efficient" ways to provide sources of protein (such as insect-based granola bars).

Analysis comments. In all these incidences, Group A framed their perceived threats and recommendations from a consumption perspective. Their responses to these questions did not address decisions that pertain to agricultural production (b1) or habitat management (b2). As such, they were not well positioned to perceive how these considerations were relevant to questions about food production sustainability.

Focus on how human consumption and climate change place stress on supply. They also argued that human technologies and changes in global systems affected the productivity of agricultural systems. They suggested that rejoining the Paris Climate Accord "help slow global warming, which would have an overreaching impact on everything else." When asked to elaborate, students argued that climate change was resulting in more extreme weather, which "is going to make it harder for farmers to yield good crops." Group A also argued that as populations increase, this will result in "less room for farmland." They stated this would also result in a greater likelihood of "soil overuse."

Group A's ideas largely came from their own personal experiences but were partly shaped by their early experiences in the course. They acknowledged that they had recently been shown a documentary about lab grown meat as part of the course, and their responses partly seem to reflect some of the views of the instructor about food production.

Characterizing rural landscapes in terms of vague quantitative factors. However, these particular students' lack of personal experiences in production agriculture resulted in less familiarity with food production supply considerations. For example, I asked whether changes in biodiversity might affect agriculture. One student initially focused on how competition from other species might impair the productivity of crops or livestock. This reflects an understanding that reductions to biodiversity can reduce losses that result from competition or predation from undomesticated species. Another student counter-argued with a general claim that all of life is interconnected: "But also one thing going extinct potentially affects tons of other things. I mean just because we don't eat bees doesn't mean that they aren't important to still be here."

While this response alludes to the interactions between biodiversity, ecosystem services, and agricultural production, Group A's overall responses suggest that they had a limited perception of how the management of rural landscapes (including cropland as well as habitats outside of fields) affected the supply of food. These students explicitly acknowledged this with statements like "I couldn't tell [if] they're doing it wrong," and, "I'm not a farmer. I have no idea" when asked to provide solutions that individual farmers could implement. One student specifically suggested that farmers should "rotate which crops they're using" as this could "minimize the space they needed"; this suggests that they viewed this particular practice more as a means for intensifying production within existing fields (b1) than for enabling ecosystem services such as soil health and pest management (b3).

Similarly, Group A demonstrated less sophistication while discussing the management of marginal lands outside of fields (b2). One student suggested that expanding fields could provide "bigger farmland" on a "mass scale" and would be important for ensuring a sufficient food supply in the future. Another counter-argued that "you can't just make more land" and stated that habitats like swamps that surround fields weren't suitable for cultivation. In most cases they did not describe these areas for their potential value as sources of ecosystem services (such as pollination, prevention of erosion, and water filtration) that can support crop production (b3, c). In general, their discussion of rural landscapes focused on quantities of land devoted to different purposes, but not to qualitative relationships among ecosystems in rural landscapes.

Summary. At this point, Group A students developed some fairly detailed and sophisticated arguments about how population growth, increases in food consumption, technologies associated with consumption affected local ecosystem and climate change, as well as the impact of all these factors on farms and rural ecosystems. Their responses primarily reflect a consumption perspective in that they predominantly addressed decisions made by consumers, not producers. Group A's lack of personal experiences in agriculture limited their capacity to frame their responses in terms of production-based decisions. This subsequently constrained their capacity to achieve the target performance. For example, they described the ramifications of climate change entirely from the perspective of how consumption will affect yields as opposed to how decisions farmers make can either slow climate change and/or mitigate its impact on food production.

Admittedly, students had only recently started the course and had not yet addressed many of the key ecological system models in the curriculum. They also showed little familiarity with the system models and disciplinary language from the course, so they were not well positioned to view this question in a manner that addressed the underlying role of ecological function in rural landscapes.

Students in Group A demonstrated some initial capacity for transferring ideas and practices from the course to real-world scenarios. For example, they recognized a correlation between the carbon footprint of beef consumption as it pertains to interactions between cropland and ecological systems (b3). However, they had very limited familiarity with production and management considerations (such as management of fields and adjacent habitats). This constrained their initial capacity to address authentic relevant contexts.

In terms of discourse, students in Group A are already demonstrating a capacity to listen to each other's ideas and build off of them. However, at this stage, these students' lack of exposure to disciplinary language and system models constrained their capacity to develop more sophisticated responses through their collaboration.

Group B – Group Discourse and Personal Engagement from Multiple Perspectives

Group B (Year 1, Shoehaven) consisted of four female students as well as an alternate. Three of these students were enrolled in an honors science course, and the instructor described some of the participants as "super talented." Most of the focus students frequently had direct experiences with food production. In particular, one student intended to go into farming as a full-time career and exhibited cattle at livestock shows. One student did lack a farm background and had no intent to go into a career related to agriculture or environmental science.

Focus on consequences of consumption. Group B was also first interviewed shortly after the course began and largely drew from personal experiences to respond to questions about threats to food production. Group B focused primarily on the impacts of growing populations on rural landscapes, identifying pollution and reduced freshwater supplies due to rising human consumption as their biggest threat. Students were also concerned about plastic pollution, stating that wild animals could eat plastic and then pass it along the food chain. Group B also advocated for purchasing certified organic products to reduce the use of "chemicals that could harm other crops and other animals."

Analysis comments. These responses reflect a mixture of consumption and production framing. Group B initially focused on how changing consumption patterns result in ramifications for agricultural production, including pollutants and reduced access to water. However, these students also addressed some production factors, including the use of certified organic production methods.

Concerns about land use. Like Group A, Group B also argued that rising populations would result in an increased demand for housing, and "that could likely take up farm space." As a follow-up, I asked if they also saw the loss of natural habitat as a threat to food production. One student argued that deforestation would "create more pollution" which would "increase production threats." When asked to elaborate, she suggested that "cutting down all these trees" would result in "a lot more air pollution." Another student expanded on this, arguing that "other natural ecosystems affect what goes on in domestic farms," adding, "bees are going extinct, but you need bees for farming."

When I asked them if they could provide additional examples, Group B also alluded to potential drawbacks from biodiversity in adjacent habitats, suggesting that food production could be harmed by “diseases in wild animals.” These students primarily relied on good/bad heuristics at this point; i.e., pollinators were good and diseases were bad. When prompted to provide more, Group B suggested that diseases in wildlife might be due to air or water pollution: “that goes back to water pollution and air pollution and it’s all about pollution.”

Analysis comments. At this stage in the interview, students in Group B are still emphasizing the implications of consumer decisions (a) while largely disregarding the implications that production decisions (b1, b2) have for the long-term viability of food production. These students are showing some preliminary capacities for transfer and discourse. Students are applying ecological considerations to production decisions and are using collaborative discourse to expand on their ideas.

Concerns about conventional production in the US. Group B’s personal experiences in production agriculture enabled them to address specific concerns about supply considerations in food production. They suggested that most crops are “generally one species or one variety,” meaning they are “particularly susceptible to certain diseases, and this can wipe out everything.” Group B went on to suggest that “it just seems more of a likelihood if there’s a larger population to feed that more monocultural crops would arise.” They advocated for buying non-GMO and/or certified organic products in stores primarily as a way to create a greater demand for more genetically diverse crops.

Group B also used their experiences to evaluate the long-term capacity of conventional agriculture in the US to respond to consumer demands. Initially, Group B expressed few concerns about the capacity of US farmers to provide a sufficient amount of food for domestic needs. They argued that “we have a lot of farmland” and the “government protects the land.”

They suggested that the greatest threats to food production existed among “third world countries” that are “unintentionally overpopulating their area.”

This led to some debate and pushback within the group. One student stated that due to widespread corn production in the Midwest, “the soil is starting to not be as fertile because of their practices.” Another added to this by suggesting that “we need to do better with crop rotating.” While students eventually agreed that soil health was not an immediate concern, they also argued “you have to do something before it gets bad.” Students suggested that crop rotation, reduced tillage, and hydroponic production systems could be useful in reversing these effects.

Analysis comments. The focus of their responses on specific production considerations (b1) at this point in the interview correlates to Group B’s more extensive background in production agriculture. Group B’s discussions also allude to an awareness of qualitative relationships between agriculture and rural landscapes. However, this was often framed primarily from the perspective of the processes that occur in managed cropland without fully addressing the systems-level interactions between cultivated fields and less-managed habitats in rural landscapes (b3).

Summary. Like Group A, Group B had only recently started the course and had not yet encountered many of the key ecological system models in the curriculum. However, the experiences of Group B were much more closely associated with production agriculture, resulting in a much greater emphasis on factors affecting food supply and a greater capacity to critique specific practices. In particular, Group B’s responses reflected their concerns about pollution, genetic diversity, resilience of cropping systems, and soil health. Despite their backgrounds in agriculture, students in Group B framed much of their discussions on decisions made by consumers.

Group B was able to draw from personal experience to provide specific recommendations for production practices, suggesting some initial capacity to transfer ideas and practices from the course to authentic contexts. However, their suggestions focused primarily on the direct impacts of consumption (a) and production (b1) on cropping systems; precise descriptions of the role of ecological interactions in rural landscapes (b2), and the dependence of agriculture on these interactions (b3, c), was largely absent from their responses. While students could identify positive or negative impacts from species in adjacent habitats (e.g., pollination vs. increased risk of disease transmission), their responses reflected good/bad heuristics even after additional prompting. For example, they suggested that the risk of disease transmission in wildlife would increase and threaten food production as pollution increased. Their responses suggest that bad outcomes are more likely to occur with other unrelated bad outcomes.

In terms of discourse, student performances from Group B were somewhat like those of Group A. While their responses were primarily individualized, students did demonstrate some capacity to listen to each other's ideas and build off them. Similarly, Group B generally lacked the capacity to incorporate disciplinary language and system models at this point, which constrained their capacity to develop more sophisticated responses through their collaboration.

Group C – Absence of Group Discourse & Personal Engagement

Group C (Year 2, Shoehaven) consisted of three students with a range of academic success. This group consisted of one male and two females. Their instructor described two of the students as high caliber and passionate about the course topics. The instructor described the remaining student as less engaged but who otherwise had satisfactory performance in the course. The instructor noted that these students had few direct experiences with production agriculture but were more engaged in the course's environmental focus in comparison to the previous year's focus group (Group B). Group C's instructor also acknowledged that they were far less "bubbly" than Group B: "They are definitely high achievers but not as outgoing...it's definitely a different focus group as compared to last year's makeup of students."

While Groups A and B were interviewed in the first couple weeks of the semester, Group C was not available for their first interview until roughly a month after the class started. Thus they had longer exposure to the course content but were still interviewed prior to the start of the Biodiversity and Extinctions unit.

Focus on demand. Like Group A, Group C initially perceived increases in demand as the principal threat: "The more people, the more food you need." When I asked why they thought this was a concern given long-term trends of increasing human populations, they responded: "Population keeps going up and you're just going to need more food." Group C also argued that food waste was a potential threat because "people are buying way too much [food] and it just ends up getting thrown out in the garbage."

Problems identified with consumption. Group C also acknowledged that human activity could result in impairments to food production, arguing that "fossil fuels and stuff are ruining the environment and oxygen." After being prompted to address the impact of biodiversity and ecosystem function, Group C worried that fossil fuel use "could disrupt photosynthesis, which is incredibly important for food production."

At the time of Group C's initial interview, I added additional questions to the interview protocol. These questions specifically prompted students to address scenarios that included both ecological and agricultural phenomena. These scenarios included identifying patterns in changes to global biodiversity, assessing claims about uses of marginal land in rural landscapes, and designing options to balance tradeoffs in production agriculture. After prompting from these questions, Group C students continued to address these questions primarily from a consumer's perspective. They expressed concerns about deforestation and air pollution that results from human activity, as this "might affect ecosystem function by depleting the amount of pollinators and important insects in the agricultural world." Students later argued that "people throwing out waste, it's also hurting [insects] along with plants and animals."

Analysis comments. Group C identified threats to food production entirely from the perspective of consumption. Similarly, their proposed solutions (e.g., reducing food waste) also reflects a focus entirely on decisions made by consumers, not producers. In addition, Group C's discourse patterns are primarily individual in nature, with very little collaboration.

Characterizing rural landscapes in terms of vague quantitative factors. Group C provided competing responses regarding usage patterns in rural landscapes. One student argued that land that isn't productive for agriculture "should be going to wildlife habitats." Another suggested that expanding fields wasn't a practical option primarily because "if you expand some of the land, and there's not enough people to take care of all that land, the food production may decrease in that case."

Similarly, when students were asked to design solutions to improve the sustainability of farming operations, they focused on factors such as the farm's size, income, and machinery. Earlier, a student worried that eventually there wouldn't be "enough people to produce the amount of food that we need." They viewed a shortage of farmers as one of the key limiting factors for future food production. When asked if they had any suggestions to improve the biodiversity and ecosystem function of habitats on farms, students responded with, "I can't think of anything" and, "I got nothing." Group C largely overlooked ecological impacts on food production unless specifically prompted and treated food production as a separate and distinct consideration in comparison to ecological function in rural landscapes.

Analysis comments. This reflected a general trend in their initial interview, namely that when reasoning about long-term viability in food production systems, they framed their responses entirely by decisions made by consumers while largely disregarding the roles of producers and of ecological stewardship.

Summary. Despite attending the same school as Group B, the content of the responses of Group C more resembled those of Group A (albeit with less sophistication). Group C's responses addressed specific outcomes of population growth, particularly increases in demand and its impact of global ecosystems (a). Conversely, they addressed supply side factors relating to managed croplands and adjacent habitats in vague quantitative terms, reflecting their general lack of personal background in this area. Their reasoning about supply side factors generally disregarded ecological considerations, even when specifically prompted. Group C's initial interview occurred before they addressed the key ecological system models of the course.

This in addition to their comparatively limited backgrounds in agriculture meant that they were not well positioned to transfer ideas and practices inherent in the course to the interview questions. In particular, students in Group C lacked prior knowledge regarding crop production (b1), habitat management (b2), and interactions between these ecosystems and cropland (b3, c).

In terms of discourse, these students rarely responded to each other or built on the ideas expressed by another student. Their performances were almost entirely individualized with almost no student-to-student dialogue in which these students could reinforce or push back on each other's ideas. At this stage, their responses generally lacked any use of disciplinary language or system models.

Initial Similarities and Differences Across Focus Group Students

There were notable similarities and differences between the three focus groups during their initial interviews. While their initial responses varied in terms of levels of detail and sophistication, Groups A and C were similar in that they predominantly focused on demand factors (a). In the cases where they did address supply side factors (b,c), their responses were less detailed and primarily relied on the use of good/bad heuristics. This contrasts with their more extensive use of system models to identify sophisticated relationships between population growth and food production (particularly among Group A). For example, Group A described relationships between population growth, increased consumption, climate change, and food production. However, their discussion of agricultural practices (such as crop rotation) largely entailed asserting that certain options were simply good or bad without addressing system models or causal mechanisms.

In contrast, Group B's responses primarily addressed factors related to crop production (b1). While they addressed some aspects related to demand (such as the potential for increased pollution from population growth), Group B more often framed their responses in terms of impacts of consumption (a) on food production itself (item b1 above). While their reasoning about demand factors (a) and environmental systems (b2) relied more heavily on good/bad heuristics, their responses about crop production reflected more of a systems level approach. For example, while they discussed pollution in terms of vague negative impacts on food production, they provided more precise responses regarding risks inherent in monocultures due to a lack of genetic diversity.

Framing and Students' Prior Knowledge. Each group of students responded to the interview questions in a unique manner. This was largely determined by how they drew on their backgrounds and experiences to frame their responses.

Group A. When asked about what they perceived as threats to future food production, Group A primarily interpreted the question as how rising populations will result in both increased demand (a) and its impact on global environments (e.g., climate change). Group A's response alluded to limiting factors that constrain a population's capacity for continuous exponential growth. Group A acknowledged that as human populations grew larger, it would become increasingly challenging to expand supply to meet demand. Group A identified several causal factors for this, including increasing impacts from habitat disturbances (b2) as well as reductions in available farmland (b3).

Even in the first weeks of the course, Group A's responses alluded to the influence of the course. Their suggestions about lab grown meat and insect granola bars appears to have emerged in response to videos shown by the teacher during class. Similarly, students acknowledged the influence of social media, and often repeated news stories they encountered on Snapchat and other programs. Group A's responses were also influenced by their experiences in their homes and with their families. A prominent example of this included climate change; two students briefly debated the validity of anthropogenic climate change, each on opposing sides of this debate.

Group B. Group B interpreted the first interview question from the lens of the impact of growing populations (a) on factors in individual fields (b1). Students in Group B were particularly concerned with the potential for impairments from to food production from threats such as pollution, reduced access to water for irrigation, losses in biodiversity (particularly pollinators), and others. Group B's responses demonstrated clear connections to the students' backgrounds in agriculture. These students addressed particular agricultural practices such as tillage and crop rotation (b1) with ease and familiarity.

Group B also adopted stances that seem to be less common among production agriculturalists as a whole. For example, Group B was surprisingly willing to adopt a critical stance on conventional practices such as monocultures and tillage; similarly, they also had favorable stances on certified organic production but not for genetically modified crops (b1). This contrasts with stances I heard most frequently while interviewing agriculturalists in my previous work (Kohn & Anderson, in press). The stances of Group B generally align with many of the sentiments of their instructor (particularly her critical stance regarding the sustainability of conventional production practices). This was also reflected in many of Group B's proposed solutions, including increased payments for conservation production practices such as crop rotation and reduced tillage.

Group C. Like Group A, Group C perceived threats to food production from a supply and demand perspective (a). However, unlike Group A, Group C responded to this question from a more simplistic linear perspective. They focused on two key trends: 1) the population continues to rise, and 2) the number of farmers continues to decrease, suggesting that they perceived a limit has been reached to the amount of food that could be reasonably produced per farmer. Group C repeatedly acknowledged they had little if any background in production agriculture, and most of their discussion was framed from the lens as a consumer of food more so than Groups A and B. Their proposed solutions often reflected their perspective as consumers (a), particularly their discussions of reducing food waste and reducing imbalances in the availability of food across the global population.

Capacity for Transfer. Each focus group's responses correlated with their personal experiences and funds of knowledge. Despite attending schools in predominantly rural areas, Groups A and C generally had life experiences outside of production agriculture. Conversely, Group B had extensive personal experiences in agriculture. This not only shaped the way they responded to the interview questions but also affected the kinds of preparation they needed from the course to successfully achieve the target performance.

The respective personal experiences and funds of knowledge of each focus group affected both their starting point on the trajectory above as well as their capacity to move along the trajectory towards the key target performance. Students in all three focus groups had limited personal experiences and funds of knowledge for addressing factors related to less managed lands in rural landscapes. As such, they were less well positioned to identify interactions between croplands and adjacent habitats, or to critique relevant production and management decisions. In cases where students referenced these interactions, their responses consisted of simple relationships (e.g., bees pollinate crops) as opposed to broader system models (e.g., sufficient levels of biodiversity and ecosystem services are needed to support food production). This seems consistent with the limited exposure students would have previously had to ecological course content based on interview responses from both teachers and students. As such, students in all three focus groups had a limited capacity to transfer ecological ideas and practices to the interview questions.

Discourse. Across all three groups, students initially demonstrated a limited capacity for listening and responding to ideas to develop more sophisticated responses. This was particularly the case for Group C, in which students rarely responded to each other's ideas. Students in Groups A and B collaborated more during their initial interviews, but at this point limitations in their grasp of relevant disciplinary language and system models limited their capacity develop more sophisticated responses through collaboration. Because students were initially interviewed two or three weeks after the start of the school year, it is likely that their course experiences had already started to shape their interview performances.

Student Needs from the Course

For students to successfully demonstrate the target performance, they needed to progress along a trajectory of supporting performances. These included:

a. Consider factors related to demand (e.g., the ramifications of population growth on consumption and global ecosystems).
b. Address supply side factors associated with patterns of land use in rural landscapes, including 1) managing crop production, 2) managing adjacent habitats, and 3) interactions between cropland and adjacent habitats.
c. Explain the mechanisms through which these factors affect crop productivity and/or system sustainability.

All students at this point had limited exposure to the system models and disciplinary language from the course needed to progress to the key target performance (c). In some cases, student responses alluded to systemic considerations such as ecosystem disturbances (e.g., climate change) and ecosystem services (e.g., pollination). However, students' limited fluency with the disciplinary language and system models limited their capacity to provide causal mechanisms for specific factors in relationship to crop productivity and system sustainability (c).

Exposure to curricular content by itself would not be sufficient to prepare students for achieving the target performance. Students would also need to gain proficiency in each of the following to do so: *framing*: the perspectives from which students perceived and interpreted the interview questions; *transfer*: students' capacities to connect ideas and practices from one context to another as a means to develop novel explanations and/or solutions for real-world considerations; and *discourse*: how students responded to opportunities to express their ideas and build on one another's ideas.

Through their course participation and their interview performances, students would be asked to address a key overarching question: *how we can improve decision making to simultaneous expand crop production while maintaining system sustainability*? Framing is a key practice for this objective; if students can only understand these issues from a single perspective, they will not be fully prepared to make fully informed decisions.

Secondly, students would need to be able to develop a capacity to transfer ideas and practices from the course to authentic scenarios. Agricultural sustainability is a considered a wicked problem; due to its complexity, it is resistant to easy solutions (Murakami *et al.*, 2017). To effectively prepare students to make more informed decisions about food production, they need to gain proficiency in transferring knowledge and practice from structured classroom settings to unstructured real-world systems.

Through the course, students in each group had varying opportunities for personal engagement with contextualized phenomena relevant to croplands and adjacent habitats. These opportunities provided regular opportunities for students to improve in their capacities for framing and transfer. Some of the focus students would gain these opportunities through the design of the FACTS curriculum, particularly through outdoor investigations and community-based experiences. Specifically, the outdoor investigations were designed to highlight the characteristics of less managed lands (b2) that affect crop productivity (b1) and system sustainability (c),. The community-based experiences, including SAEs, field trips, and guest speakers, were partially intended to provide students with meaningful exposure to supply side factors, particularly managing crop production (b1) as well as interactions between cropland and less managed lands (b3).

Finally, students would need opportunities for group discourse to achieve the interview target performances. Through group discourse, students gain more frequent and more meaningful opportunities to learn and utilize disciplinary language and system models to reason and express their ideas. In comparison to scaffolded individual writing and whole-class discussion, students who primarily participate through group discourse are more personally accountable for developing explanations and solutions. These opportunities increase the extent to which students are fluently capable of applying disciplinary language and system models in a real-time environment. Group discourse also provides greater opportunities for students to identify connections across curricular content and with their own personal experiences. Furthermore, the greater the extent to which students learn through group discourse, the more their preparation resembles the tasks they would continue to perform in each subsequent interview.

Classroom Narratives

The overarching goal for both classroom learning and situated learning opportunities was to enable students to expand their repertoire by identifying connections and tradeoffs between food production and ecological factors such as biodiversity, ecosystem services, and resilience. Each focus group encountered differences in teacher implementation of the curriculum and variances in their learning environments that affected their capacity to achieve the target performance. These differences are summarized in the following section.

Group A – Group Discourse and Personal Engagement with Limited Perspectives

School Setting. Group A (Year 1) attended Lanesville High School. Lanesville is a small town in a Midwestern state with a population of just under 1300. Lanesville is within a half hour drive of a state capitol and a major university. It is surrounded by a mixture of farmland, lakes, and natural areas and is within a short drive of multiple state recreation areas. Lanesville High School is classified by NCES as Rural: Distant and enrolls 364 students, of whom 93% are white. Roughly one fifth of the student population is eligible for free or reduced-price lunch. The program consisted of what the instructor described as a mixture of "lake kids" and "farm kids"; i.e., most students had affiliations either with homes built on the surrounding lakes or with production agriculture. The community was evolving from a farming community to a bedroom community. The instructor stated that, "a lot of people that live out here have moved out from [nearby cities]. They're doctors and lawyers and professors." As a result, "only a small handful" of students enrolled at the high school were from a traditional agricultural background.

Teacher's Background. Mrs. E is the agriculture instructor at Lanesville High School. At the time of this study, she had six years of teaching experience. Mrs. E volunteered to be a part of the FACTS study because she was interested in using her courses to improve students' decision-making capabilities, especially in their future careers. Mrs. E lives on one of the surrounding lakes but has close connections with many agriculturalists in the community as the FFA advisor.

Mrs. E had first utilized the curriculum during the pilot phase in the 2018-19 school year. As such, she was "more familiar" with the content and felt confident in her capacity to implement instruction using the curriculum. Mrs. E is certified to teach both agriculture and biology, and some of her classes were offered for science credit. Mrs. E contrasted her teaching philosophy with the more traditional approaches utilized by other science teachers in her building, particularly their perceived emphasis on the memorization of rote content and procedures.

Mrs. E sought to implement the curriculum as it was designed: “I do it by whatever the instructions are.” She implemented units in the same order in which they were posted on the FACTS website and followed the same order of activities for each unit. She was able to complete the first two sections of the course, but not the third section (individual and societal sustainability) before the end of the semester. This final section of units was designed to provide students with explicit transfer opportunities to define problems within their own communities and that result from both production and consumption decisions that impair biodiversity and ecosystem function. While students had opportunities to investigate interactions within less managed lands and considered demand and supply side factors, their actual opportunities to engage in transfer were more limited than what was intended in the curricular design.

Introductions to Units. Mrs. E began each unit with the Data Dive activities that were included in each unit for Day 1. The Data Dives utilize research data and case studies to introduce students to an anchoring phenomenon for each weekly unit. Each Data Dive guides students in identifying patterns in case study evidence as a means to develop questions, construct explanations, and engage in evidence-based argumentation.

During my first interview with Mrs. E, her students had just completed the Extinctions Unit. In this case, students were provided with graphed data from the IUCN Red List comparing extinction rates among birds, amphibians, and mammals. They were asked to develop conclusions based on patterns they identified in the data in their assigned groups. The curriculum then prompted students to construct explanations based on the trends they observed and link these outcomes to potential causal mechanisms. These prompts provide written and oral opportunities for students to ask questions and express ideas in individual, group, and whole-class settings.

Table 2 – Summary of Introduction to Units for Group A

Item	Phenomena	DCIs	SEPs	CCCs	Discourse Type
IUCN Red List Data Dive	Comparative extinction rates	ESS3.C: Human Impacts on Earth's Systems LS4.D: Biodiversity & Humans	Asking Questions/ Defining Problems Evidence Based Argumentation Constructing Explanations/ Designing Solutions	Patterns Cause & Effect	3) Students use valid evidence & models to support their claims.

In addition, the appendix provides suggestions for supporting productive classroom discourse through the use of options such as the 9 Talk Moves (see Appendix E). However, teachers are given the final authority for how they choose to implement their instruction. Mrs. E opted to use whole class discussion as an opportunity to discuss multiple interpretations of the data. Her approach framed this activity as an opportunity for collaborative sensemaking: "Then I say "Does anybody agree with that, disagree with that? If so, why?" Mrs. E's description of her implementation encourages divergence initially, allowing for multiple interpretations:

> Then we'll have a group conversation that way because in that Data Dive especially, you could say, 'I saw this' but somebody else might think of something different that they interpreted on there. That isn't wrong, it's just nobody else thought about it in that aspect. Then we go over all the answers that way.'

Mrs. E's priority was for students to have "good discussions" at this stage. Instead of "getting the right answers", she emphasized student reasoning about the anchoring phenomenon. This centered student ideas as the initial driving factor in her instruction.

Analysis comments. Mrs. E's implementation of the Day 1 activities provided key opportunities for students to engage in framing, transfer, and discourse. Students had opportunities to ask questions and make predictions about how changes to biodiversity relate to decisions made by consumers as well as those engaged in production and stewardship of rural ecosystems. These exercises also prepare students for transfer by contextualizing ideas and practices from each unit in specific case studies. Additionally, through an emphasis on group discourse, students had key opportunities at the outset of each unit to listen to ideas, engage with them, and build more sophisticated explanations.

Unit Implementation. The weekly units are designed to provide students with core ideas on Day 2. The curriculum provides driving questions as well as introductory videos that provide a brief (~3 minute) overview of the core concepts. Students then are provided with a PowerPoint consisting of a mixture of core concepts and prompts for group or whole class discourse. These activities prompt students to develop and refine ecological system models based on patterns between biodiversity, ecosystem services, carrying capacity, and resilience. Students are also guided in identifying causal mechanisms to describe how interactions from agricultural production and resource consumption affects ecosystem function. This directly correlated to the kinds of real-world scenarios focus students would encounter during their focus group interviews. Mrs. E continued to prioritize discourse during these lessons but also alluded to challenges inherent in this approach: "...it takes longer because there's always discussion or interruptions, classroom management-wise, there."

At this stage, students in Group A's class encountered mixture of comparing and critiquing ideas as well as identifying 'correct answers' to the unit's driving questions based on the PowerPoint content:

> As we're doing [the PowerPoint], they're answering their questions. Some of the kids wait until they're done because they want to listen ... some kids can't answer and go. Some of the kids pick up on, "Gosh, there's the answer to this one right here." Some of the kids are like, "Oh, that's an answer to a question?" They don't make that connection yet. It just depends on what level they're at.

In the Extinctions Unit, the curriculum guided students in identifying patterns between biodiversity and the capacity of a region for photosynthesis (i.e., warmer, wetter, sunnier areas tend to have the greatest biodiversity). They were then provided with data regarding the estimated rate of global extinction (6-8 species per hour) and the types of human activity responsible for most of these extinctions. Students were also introduced to the concept of the extinction vortex, which provides an explanatory model to address how the loss of one species increases the risk of extinction for other species in that ecosystem. At the conclusion of Day 2, students were prompted to “revisit your explanations from the previous day’s activity and add details or corrections as needed.” When time allowed, students went back into a group Google document to update their Day 1 responses.

Table 3 - Summary of Implementation of Units for Group A

Item	Phenomena	DCIs	SEPs	CCCs	Discourse Type
Extinctions Unit Core Concepts	Extinctions & Human Causes Extinction Vortex	ESS3.C: Human Impacts on Earth's Systems LS4.D: Biodiversity & Humans LS2.A: Interdependent Ecosystems Relationships LS2.C: Ecosystem Dynamics, Functioning, and Resilience	Developing & Using Models Constructing Explanations/ Designing	Systems & System Models	2) Students collaborate to develop more sophisticated explanations and solutions. 5) Students align their responses with scholarly or professional norms & language.

On Day 3, the curriculum provides students with an investigation related to the anchoring phenomenon and driving questions. In the Extinctions Unit investigation, students in Group A's class looked for evidence of the primary causes of human-caused extinctions (habitat loss, invasive species, pollution, and overharvesting) on their school's campus. This provided a preliminary means to characterize the causal mechanisms through which agricultural production and resource consumption can impair biodiversity, ecosystem services, and resilience; these students would explore these in greater detail over the remainder of this section of units. This also provided a place-based opportunity for students to ask questions and make predictions about the causes and effects of changes to ecosystem interactions. Furthermore, students were guided in defining the problems that emerge from these interactions using the system models described in Day 2.

Mrs. E modified the lab, changing the focus from a school habitat to the entire campus of the school: "We literally started back here at the greenhouse, went all the way up by the barns, the woods, the ball fields, the parking lots through the front of the school and back around." Mrs. E felt that this was a more successful approach because it provided students with greater exposure to interactions between developed and less-managed lands in comparison to a school forest or similar habitat.

Mrs. E divided students into teams. They then acquired evidence to defend a stance as to whether a particular disturbance was present on the school's campus. These students then presented their conclusions to the rest of the class for critique and debate. They recorded their responses and revisions in a shared Google document. Mrs. E prioritized achieving group consensus around the findings of each investigation: "We will come back together as a whole class and answer the questions from every assignment. I've built in time. ... For feedback, sooner is better." This enabled students to improve on their capacities to collaborate to develop more sophisticated explanations and solutions.

Table 4 - Summary of Unit Investigations for Group A

Item	Pheno mena	DCIs	SEPs	CCCs	Discourse Type
Habitat Threat Assessment	School campus as a habitat disturb-ance	ESS3.C: Human Impacts on Earth's Systems LS4.D: Biodiversity & Humans	Asking Questions/ Defining Problems Developing & Using Models Evidence-based Argumentation Constructing Explanations & Designing Solutions	Patterns Cause & Effect Systems & System Models	1) Students listen to their group member's ideas to reinforce or push back on their ideas. 2) Students collaborate to develop more sophisticated explanations and solutions. 3) Students use valid evidence & models to support their claims.

Throughout the Day 3 Investigations, students were prompted to identify evidence, look for patterns, and draw conclusions about interactions between human-managed ecosystems and less managed areas in rural landscapes. Students were guided in developing evidence-based arguments about these interactions during individual, group, and whole-class performances. They developed and revised their explanations in a manner similar to the kinds of performances they would be asked to provide in their later interviews.

Analysis comments. Throughout the unit implementation, students are again engaged in opportunities for framing, transfer, and discourse. Students have opportunities to frame connections between ecological sustainability and agricultural production through course content that emphasizes both consumption and production considerations. Admittedly, students have limited opportunities for transfer while addressing core ideas on Day 2. However, in cases where students were able to take part in investigations in local habitats, students connect classroom performances with local landscapes and ecosystems. In cases where students were unable to go into actual habitats, they also had some opportunities for authentic engagement within their classrooms, albeit to a lesser extent.

Finally, students in Mrs. E's class continued to gain daily opportunities to engage in group discourse. This would have provided additional opportunities to express their ideas and build on one another's ideas in a collaborative fashion. In addition, students would have had opportunities to expand their fluency in using new disciplinary language and system models each week.

Unit Conclusion. On Day 4, the curriculum provides opportunities for review and assessment. The curriculum prompts students to revisit the unit's driving questions and rank their comfort in addressing each (1 = completely unsure; 3 = completely sure). Mrs. E modified this component to offer more opportunities for sensemaking through group discourse:

> Each group gets certain questions and then the other groups have to go and comment on the other groups' [responses to] questions. It can't just be, "Great job." You've got to give some substance of why you refute, dispute, agree with [their response] or need to add on something.

In this way, students had additional opportunities for consensus around the driving questions supported by criteria from their instructor for achieving an effective performance:

> If they didn't think their information was correct, they had to write down below, 'I don't feel that you have it correct and this is why.' Or they had to put on there, 'I agree with what you're saying and this is why but you also need to consider this factor.'

These additions further reflected Mrs. E's expectations for her students to provide evidence-based arguments and model-based explanations in group and whole-class discourse. This provided additional opportunities beyond the curricular design for students to collaboratively reason about patterns between human activity and ecosystem function.

Furthermore, these sessions provided potential moments to define problems and reach consensus about causal mechanisms for how agricultural production and resource consumption can impair biodiversity, ecosystem services, and resilience.

Table 5 - Summary of Unit Conclusion for Group A

Item	Phenomena	DCIs	SEPs	CCCs	Discourse Type
Extinctions Review & Assessment	Extinctions & Human Causes Extinction Vortex	ESS3.C: Human Impacts on Earth's Systems LS4.D: Biodiversity & Humans	Developing & Using Models Evidence-based Argumentation Constructing Explanations & Designing Solutions	Patterns Cause & Effect Systems & System Models	1) Students listen to their group member's ideas to reinforce or push back on their ideas. 2) Students collaborate to develop more sophisticated explanations and solutions. 3) Students use valid evidence & models to support their claims. 5) Students align their responses with scholarly & professional norms & language.

Students in Group A's class completed the assessments included in the curriculum. These consist of a mixture of multiple-choice questions (some of which ask for justifications) as well as essay questions that prompt a three-dimensional performance. While not all questions are fully three-dimensional, these assessments are intended to provide both teachers and students with insights into student progress on the unit objectives and target performances. For example, Extinctions Unit assessment questions include asking students to predict how the risk of extinction for a given species can be impacted by geographical considerations (e.g., equatorial vs. alpine ecosystems) and how the rate of extinction affects human activity like agriculture. Students completed the weekly assessments individually, which provided Mrs. E with an opportunity to identify gaps in understanding.

In addition, students could complete a voluntary quiz outside of class that Mrs. E developed based on unit vocabulary. In the past had struggled with the disciplinary language of the course. Mrs. E added voluntary vocabulary quizzes to improve students' capacities to align their performances to the conventions and language of ecology during discourse.

Analysis comments. The Day 4 review and assessments provided students with a key opportunity to address the course content from producer and ecological stewardship perspectives. For example, the driving questions for the Extinctions Unit address both production and consumption-based causes of biodiversity loss. Furthermore, students address the ramifications of these disturbances from a habitat management perspective through concepts such as species niches and interdependent ecological interactions.

Students also engaged in a key opportunity for transfer through these activities. In particular, students needed to apply the ideas and practices from the course to address three-dimensional prompts about authentic contexts. In the Extinctions unit, these include addressing hypothetical comments students could encounter through in-person or online interactions as well as critiques of legal protections for threatened species.

Finally, while students completed their quizzes individually in most cases, their preparation for the quiz reflected another key opportunity for group discourse. In particular, these students critiqued each other's ideas and identified ways in which to improve the accuracy and sophistication of responses from other students.

Situated Learning. On Day 5, the curriculum provides students with Career and Community Connections. These are lessons designed to help students identify connections between the content of the course, their personal lives and career aspirations, and their local community. These components guide students in determining a particular career path and developing skills in writing resumes and cover letters (a priority in agriculture courses as part of career and technical education).

In addition, the Day 5 components provide students with discourse prompts to identify ways in which the unit content might relate to decisions they will make as adults and/or to decisions adults make in their local communities. This was designed to provide discourse opportunities for students to apply ecological system models to define problems and develop solutions in authentic local contexts. The curriculum prompts teachers to separate students into groups based on their personal experiences and career aspirations to promote deeper connections between the curricular content and students' interests. The intent is to eventually transfer from group to whole-class discourse by the end of class to provide opportunities for students to consider the unit's content from differing perspectives (e.g., demand vs. supply side).

At this point in the semester (several weeks after the start of the school year), students had not completed any of the Day 5 activities. Mrs. E stated that she "held them off because that's what I want them to do next week for two days when we're gone to the National [FFA] Convention." Students in Group A's class were also responsible for managing the school's recycling bins. This limited the time available for the Day 5 activities. In addition, Mrs. E's emphasis on discourse required additional time in comparison to what was provided in the curriculum.

In the Extinctions Unit, the curriculum prompts students to work in small groups to identify what was personally relevant and how this unit might affect decisions they would make in their future career. Students in this class did not have opportunities to utilize these discourse opportunities to explicitly connect the unit content to student's individual backgrounds and career aspirations. As Mrs. E explained, "If there were those conversations, then they did it within their groups and I might not have gotten around there. Maybe that might be something that should be done as a full group more." This meant that students had less weekly exposure the full array of demand and supply-side factors inherent in the focus group interview questions than was intended in the curricular design.

Table 6 - Summary of Day 5 Situated Learning Opportunities for Group A

Item	Phenomena	DCIs	SEPs	CCCs	Discourse Type
Extinction Day 5	None (career preparation)				4) Students incorporate their lived experiences to add context and nuance.

Shortly after this interview, Mrs. E did schedule a field trip to a local university so that students could gain meaningful exposure to supply side factors related to managing crop production and interactions with less managed lands. This trip emphasized research and strategies that balance tradeoffs in agriculture production, such as "the equipment they use to drill stuff into the fields to be more sustainable with our soils." She felt that this provided a meaningful opportunity for students to identify mechanisms through which less managed lands affected and are affected by agricultural production:

> We were literally just talking about overharvesting and human-managed areas. They got to connect all things that we talk about. That was really good, to have that live field trip. They were making a connection, "Hey, there's less biodiversity here. That means there's less ecosystem services.

This opportunity provided students with what may have been their most explicit opportunity to consider the interactions between cropland and adjacent habitats (particularly those without a background and/or SAE opportunities in production agriculture). While these interactions are strongly emphasized in the spring Horticulture & Agronomy course, the fall Natural Resources course focuses more on interactions within less managed lands. Interestingly, the Group A focus students' descriptions of this field trip more emphasized the career aspects:

> It allows you to see all of the different job opportunities that are within just a field that you think of so generally as just like agriculture. And there's so many different specific jobs that you can actually make really good money from when you go into that field. Seeing a lot of successful people in those fields was cool.

In addition to SAEs and field trips, Mrs. E regularly sought to situate the curricular content in contexts relevant to the local community. When feasible, she enthusiastically opted for investigations in outdoor settings as opposed to the laboratory alternatives. She and her students reported that these experiences were particularly valuable for identifying connections between three-dimensional performances in the classroom and real-world contexts.

Table 7 - Summary of Field Trip Situated Learning Opportunities for Group A

Item	Phenomena	DCIs	SEPs	CCCs	Discourse Type
University Field Trip	Conservation Agriculture	ESS3.C: Human Impacts on Earth's Systems ETS1.B: Developing Possible Solutions LS4.D: Biodiversity & Humans	Constructing Explanations/ Designing Solutions	Cause & Effect Systems & System Models	4) Students incorporate their lived experiences to add context and nuance. 5) Students align their responses with scholarly & professional norms & language.

However, Mrs. E generally compartmentalized the curricular content from the career preparatory components of the course. While she required students to complete at least 15 hours of community-based job shadowing in addition to cover letters and resumes, these components of the course were generally disconnected from her emphasis on sensemaking through classroom discourse. She also was unable to utilize the Day 5 discussion prompts that explicitly connected course content to students' career ambitions and lived experiences. Except for the field trip, many of her students (especially those without a background/SAE in production agriculture) would have very limited exposure to how the course content related to specific decisions made in supply-side scenarios in the fall semester course.

Analysis comments. Students in Group A's class had mixed opportunities to improve in their capacities for framing, transfer, and discourse during their Day 5 activities. Their exposure to authentic contexts through their SAEs, field trips, recycling and other situated opportunities would have especially enhanced their capacity for transfer. Students experienced real-world systems while engaged with the course content in a manner that would have frequently made the connections between the classroom and real world more explicit and meaningful.

However, the compartmentalization of the career-based experiences from the course content also meant that students had less exposure to frames related to production-based perspectives than could have been achieved. This is particularly the case given that the Day 5 discourse prompts that were designed to provide multi-perspective exposure were substituted for managing the recycling program. While students reported motivation from this activity (supporting transfer), this change primarily reflected a consumption perspective. Similarly, this change also meant the loss of a key opportunity for students to engage in group discourse.

Patterns of student engagement. In general, Mrs. E's implementation prioritized sensemaking through classroom discourse. Students had opportunities beyond the design of the curriculum to express their ideas individually, in small groups, and as a class both in writing and orally. The implementation of the curriculum guided students in expressing divergent ideas and using evidence and system models to reach a consensus over the course of the unit. While students could have multiple interpretations of evidence during the Day 1 Data Dives, students were guided in developing a common understanding of the anchoring phenomena and core ideas of each unit. By the review and assessment portion of Day 4, students were expected to provide evidence (what Mrs. E regularly calls "substance") for their claims based on the unit content.

Mrs. E reported that she often extended time for these options during her instruction: "We get into great discussions, sometimes that day turns into two periods and a half instead of one period. I think it's well worth it because I think they're understanding the material better." Mrs. E used discussions to revise their reasoning and conceptual models, which they tracked in a shared Google document. She noted that this provided opportunities for students to make deeper connections with the content: "They're offering answers in class discussions and they're excited about, 'Oh my God, I got this'."

Mrs. E's approach to implementation likely had mixed implications for student performances during their focus group interviews. In some ways, Mrs. E's expanded emphasis on collaborative sensemaking through discourse supported focus student interview performances. Mrs. E's students had additional opportunities beyond the curricular design to collaboratively ask questions and define problems about ecological disruptions and ramifications that can emerge from food production and resource consumption. However, this choice resulted in tradeoffs. The additional time needed for discussions in addition to losses of time due to managing the recycling program resulted in a general inability to provide opportunities for students to contextualize questions and problems in relevant and authentic contexts. As a result, students had less exposure to the full array of demand and supply-side considerations that they otherwise might have had with full implementation of the Day 5 activities.

Perceived Successes & Challenges. Mrs. E noted that while students struggled with the initial units on matter and energy and cell biology, some had noticeably stronger engagement and performances starting with the biodiversity and ecosystems unit. She explained that students' prior experiences (or lack thereof) in biology and chemistry affected their capacity to achieve the target performances for the class. Additionally, some upperclassmen had become accustomed to a less rigorous agriculture courses and transferred out of the course at the end of the semester because they "thought it was too hard."

Mrs. E observed disparities between the "lake kids" and "farm kids" regarding the relevance of the content to students' personal backgrounds. She explained that students who managed the school experimental field had already utilized grants to purchase equipment to implement more sustainable conservation agriculture practices such as reduced tillage (including practices they observed firsthand during a field trip). Students who had personal connections to surrounding lakes demonstrated far more interest in topics like aquatic invasive species.

Mrs. E noted that some students were "missing that connection" between the course content and decisions they would personally make in their lives and careers. This seems to be due in part to the limited use of the Day 5 activities intended for this purpose. While students had extended opportunities to engage in collaborative sensemaking through discourse, they had fewer opportunities to identify explicit connections between the units and their personal funds of knowledge. They also had limited meaningful exposure to the supply side factors that are less emphasized in Natural Resources curriculum.

Additionally, extending time for discourse meant that students were unable to take part in units designed specifically for the purpose of helping students connect the course content to personal decisions in their local communities. While some students were able to acquire these opportunities through alternative opportunities (e.g., FFA members and the school experimental field), those without access to these opportunities lacked the same kind of meaningful exposure.

Group B – Group Discourse and Personal Engagement from Multiple Perspectives

School Setting. Group B (Year 1) attended Shoehaven High School. Shoehaven is a small town in a northeastern state with a population of 816. Shoehaven High School is classified by ***NCES*** as Rural: Distant and enrolls 385 students, of whom 94% are white. Over 40% of the student population is eligible for free or reduced-price lunch.

The instructor reported that her class enrollment consisted of numerous FFA members and traditional 'farm kids' with direct connections to production agriculture. Shoehaven was considered the "breadbasket of the American Revolution" and production agriculture continues to be prominent throughout the surrounding area. The instructor reported that there was a mixture of conventional and traditional approaches to production agriculture among farmers in the area: "We have some fairly modernized farms and we have some that are still stuck in the '70s and '80s." She also reported that her school's science teachers were increasingly adopting NGSS-aligned instruction in their classrooms, and that she had support from her administration for aligning her agriscience courses to NGSS.

Shoehaven was heavily damaged by extensive flooding because of a hurricane in 2011, which resulted in severe economic losses to farms in the area. The instructor observed that students often still reacted to the community siren that signals at noon due to the traumatic experiences from this event.

Teacher's Background. Mrs. B is the agriculture instructor at Shoehaven High School. At the start of this study, she had five years of teaching experience, but this was her first-year teaching at Shoehaven. Mrs. B volunteered to be a part of the FACTS study in part because she believed agricultural education should prepare students to balance ecological and economic sustainability. Mrs. B farmed with her husband and also had a professional background in biotechnology. Mrs. B used her backgrounds in these fields to routinely ground class discussions in specific contexts in the surrounding community. This positioned Mrs. B with additional authenticity and expertise as an instructor.

Mrs. B's instruction emphasized a "systems-based approach" in which she routinely connected "real life examples" in agriculture to broader underlying themes inherent in the course content. Mrs. B valued group discourse for improving informed decision-making as a key part of her instruction with the intent of supporting "open minds instead of open mouths". She enthusiastically responded to my requests to integrate student's career interests and personal experiences into classroom discussion and utilized the prompts that are embedded in the FACTS curriculum for this purpose.

Mrs. B prioritized critical sensemaking and informed decision-making over more traditional approaches to career preparation in agricultural education. She alluded to this when she described her goals for the course: "We're not learning about environmental science so that we can go and enjoy our state parks. It's to ensure that we have enough natural resources and the services that we get from ecosystems." For Mrs. B, the course existed primarily to address the question of "How does this impact my choices in the long run?" This was reflected in her choice to use the Day 5 discussion prompts in lieu of the more traditional aspects like resumes and cover letters.

Like Mrs. E, Mrs. B generally implemented the curriculum based on its intended order and design. Similarly, she was not able to complete the curriculum, and had only reached the soil and water pollution unit by the end of the semester. As such, students at Shoehaven had fewer opportunities to connect course concepts to decisions within their own personal lives and local communities than originally intended in the curricular design. However, Mrs. B was able to utilize the discussion prompts in the Day 5 Career and Community Connections activities; as such, her students would have had more exposure to this aspect of the curriculum than Mrs. E's students.

Introduction to the Units. At the time of our first interview, Mrs. B's students had recently completed the Biodiversity and Ecosystems Unit (which occurs before the Extinctions Unit). Students each received a paper copy of the entire weekly unit's packet. They began by self-assessing their capacity to answer the unit's driving questions on a 3-point scale (fully understand, partial understanding, don't understand) as a means to connect each unit to their existing funds of knowledge. The driving questions in this unit primarily addressed how levels of biodiversity in an ecosystem correlate to levels of ecosystem services and resilience to disturbances.

This activity was followed by the Data Dive and anchoring phenomenon. In this unit, students began by observing tabletop saltwater ecosystems consisting of brine shrimp and algae they had created during the previous week. This activity provided a bridge between the cellular and atomic-molecular concepts that they had addressed in the previous units (Matter & Energy and Cell Biology) and the macro-level and ecosystem concepts in this unit.

The curriculum prompts students to first observe their ecosystems before addressing all the forms of matter and energy that they can identify within these closed systems. The curriculum then asks a variety of questions, including if students think that the sealed beakers will run out of oxygen, and whether they think that the algae or the shrimp are more important (with justifications required for every response). This is meant to prepare students to reason about interdependent ecosystem relationships using system models through individual writing, group discourse, and whole-class discussion.

Table 8 - Summary of Introduction to Units for Group B

Item	Phenomena	DCIs	SEPs	CCCs	Discourse Type
Tabletop Ecosystems Data Dive	Algae & brine shrimp ecosystems	LS2.A: Interdependent Ecosystems Relationships LS2.C: Ecosystem Dynamics, Functioning, and Resilience	Asking Questions/ Defining Problems Developing & Using Models	Cause & Effect Systems & System Models	2) Students collaborate to develop more sophisticated explanations and solutions.

Mrs. B acknowledged that she initially struggled to support productive classroom discourse. This was due to an unexpectedly wide range of learning abilities in her classes that year:

> I have one non-verbal student, and then I have some students that read at a fourth and fifth-grade level. All the way out to kids that are in the top 10 of their class. It's definitely a variety of skills.

Because of this range in abilities, Mrs. B found it challenging to support group discourse without a prior “full on discussion together”. She adopted the ranking system for the discussion questions prior to each Data Dive because they felt that this better prepared her “lower skills students” for group discussions. The need for greater amounts of teacher scaffolding limited opportunities for more student-driven discourse. To facilitate these efforts, Mrs. B kept students in the same mixed-ability groups throughout the semester. This allowed students to become increasingly comfortable and effective while engaging in collaborative sensemaking to develop more sophisticated explanations and solutions.

Analysis comments. Students in Group B's class experienced differences in the Day 1 implementation that affected their opportunities for framing, transfer, and discourse. Like Group A, students in Group B's class had opportunities to ask questions and make predictions about production and ecological stewardship in authentic case studies. However, due to the wide range of abilities, these students had fewer opportunities for un-scaffolded group discourse. As such, they lacked the some of the opportunities Group A's class had to listen to ideas, engage with them, and build more sophisticated explanations.

Unit Implementation. Students encountered differing opportunities for addressing the core ideas on Day 2 depending on the make-up of their classes in each of the three sections of this course. When feasible, students addressed the core ideas primarily through group discourse: "They're able to go through it on their own, take notes and do jot some of their ideas to the group discussion questions and then we all come back as a group." However, for other students, Mrs. B verbally summarized each PowerPoint slide before breaking them into small groups to individually address and summarize how the content related to the driving questions.

All students transitioned from small group discourse to full group discussion by the end of the Day 2 activities to revoice and critique ideas while working towards a consensus. For example, in the Biodiversity and Ecosystems unit, students would have had the opportunity to identify patterns between levels of biodiversity and an ecosystem's carrying capacity, and how this affects ecosystem services and resilience. This unit also prompts students to address how biodiversity is intentionally limited in human-managed ecosystems to maximize the availability of a specific ecosystem service (e.g., food production). This was a key system model that focus students would need to provide successful interview performances.

Table 9 - Summary of Unit Implementation for Group B

Item	Phenomena	DCIs	SEPs	CCCs	Discourse Type
Biodiversity & Ecosystems Unit Core Concepts	Biodiversity, ecosystem services, & resilience Human-managed ecosystems	LS2.A: Interdependent Ecosystems Relationships LS2.C: Ecosystem Dynamics, Functioning, and Resilience LS4.D: Biodiversity & Humans	Developing & Using Models Constructing Explanations/ Designing	Cause & Effect Systems & System Models	2) Students collaborate to develop more sophisticated explanations and solutions. 5) Students align their responses with scholarly/ professional norms & language.

Students began the Day 3 Investigation by briefly returning to their ideas about their tabletop ecosystems from Day 1. They were prompted by the curriculum to revise their initial ideas about cellular-level transformations of matter and energy among the shrimp and algae. Furthermore, students incorporated disciplinary language and system models to explain how changes at the molecular and cellular levels enabled the ecosystem to function.

Students then used a computer simulation to make predictions about differences in the amount of biomass that could be supported among grass, rabbits, and foxes in a hypothetical ecosystem. In both the tabletop ecosystems and meadow simulation, students engaged in a mixture of private writing, group discussion, and whole-class presentations. Mrs. B used the 9 Talk Moves and other resources to guide discussion and help students collaboratively revise and refine their ideas.

Table 10 - Summary of Meadow Simulation Investigation for Group B

Item	Phenomena	DCIs	SEPs	CCCs	Discourse Type
Meadow Simulation	How many foxes can a meadow support?	LS2.A: Interdependent Ecosystems Relationships LS2.C: Ecosystem Dynamics, Functioning, and Resilience	Developing & Using Models Evidence-based Argumentation Constructing Explanations & Designing Solutions	Patterns Cause & Effect Systems & System Models	2) Students collaborate to develop more sophisticated explanations and solutions. 3) Students use valid evidence & models to support their claims. 5) Students align their responses with scholarly & professional norms & language.

Analysis comments. Students in Group B's class experienced some similarities to Group A's class during the unit implementation. Through the course content, students had opportunities to identify connections between ecological sustainability and agricultural production. Similarly, students in Group B's class gained valuable opportunities for transfer from investigations that were situated in local habitats. These investigations also provided valuable opportunities for students to engage in group discourse to express their ideas and collaborate to revise and improve their explanations and solutions.

Unit Conclusion. Mrs. B stated that she utilized an "assortment of reviews" to prepare students for the Day 4 assessments. Students first had opportunities for private preparation, including time in class to prepare handwritten 3x5 notecards for the quiz as suggested by the curriculum. Mrs. B also used the *Gimkit* program to convert a multiple-choice quiz into an interactive review game consisting of mostly one-dimensional concepts from the units. Mrs. B opted to use this because students “enjoy that break” while having the chance to “see what they’re doing and where they’re at before the quiz.”

Students completed both the individual multiple-choice quiz as well as the group quiz with short answer questions. While they could collaborate with their groups, they had to submit their own written answers individually to prevent groups from relying on a particular individual. Mrs. B felt that students “really benefited from the group discussions” that resulted from this approach.

Table 11 - Summary of Unit Conclusion for Group B

Item	Phenomena	DCIs	SEPs	CCCs	Discourse Type
Biodiversity & Ecosystems Review & Assessment	Biodiversity, ecosystem services, & resilience Human-managed ecosystems	LS2.A: Interdependent Ecosystems Relationships LS2.C: Ecosystem Dynamics, Functioning, and Resilience LS4.D: Biodiversity & Humans	Developing & Using Models Evidence-based Argumentation Constructing Explanations & Designing Solutions	Patterns Cause & Effect Systems & System Models	1) Students listen to their group member's ideas to reinforce or push back on their ideas. 2) Students collaborate to develop more sophisticated explanations and solutions. 3) Students use valid evidence & models to support their claims. 5) Students align their responses with scholarly & professional norms & language.

In the Biodiversity and Ecosystems unit, students would encounter a variety of opportunities to develop arguments from evidence to provide explanations or solutions. For example, the first question asks students to develop an explanation for why equatorial ecosystems tend to have more ecosystem services and greater resiliency than those located at the poles or mountaintops. Another question asks students to summarize how and why human managed ecosystems differ from naturally occurring habitats, and how changes to biodiversity affect ecosystem services and resilience.

Analysis comments. Students in Group B's class had key opportunities to frame the course content from producer and ecological stewardship perspectives during their assessments. For example, in the Biodiversity and Ecosystems unit, students are prompted to explain how and why human managed ecosystems are different from naturally occurring ecosystems in terms of biodiversity, ecosystem services, and resilience. This positions students to reason about agricultural production from an ecological perspective. Students must also apply the ideas and practices from the course to address questions about authentic contexts. This would support students' preparation for transfer.

In terms of opportunities for discourse, students in Group B's class experienced different opportunities than Group A. In particular, students in Group B's class worked primarily individually and in whole-class activities to prepare for their quizzes. However, they were allowed to work in groups to develop answers to the short-answer questions. Mrs. B reported that these were valuable opportunities for students to "bounce ideas off of each other". This would have prepared students for the kinds of discourse they would utilize in their interviews.

Situated Learning. Mrs. B intended to provide a slow, gradual transition to a universal SAE requirement for each student to minimize pushback. Mrs. B noted that her students often already engaged in activities that were similar to an SAE experience. These included raising and exhibiting cattle, part time employment in AFNR settings (including Mrs. B's farm), home gardens, and competing in the World Food Prize competition.

Mrs. B felt that it was "absolutely feasible" to use the Day 5 discussion prompts to identify connections between the content and students' career goals and intended to increasingly implement these aspects over the remainder of the semester. For this unit, the curriculum prompts students to determine how biodiversity and ecosystem services might be relevant to specific decisions they might make in their future careers. Furthermore, students are prompted to discuss how their career paths might currently impair biodiversity, the ramifications that could result from this, and how they might change aspects of their careers to mitigate these effects.

Mrs. B also incorporated these discussions on Days 1-4. Mrs. B regularly contextualized course content using local examples that were more relevant to students' backgrounds. For example, both Mrs. B often referenced a nearby corn field that most students passed on their way to school. This field often served as a useful example for interactions between cropland and less managed habitats, particularly in comparison to neighboring farms that have adopted conservation agriculture practices:

> We see some really sustainable practices but we're also seeing some that aren't, but also aren't getting the negative attention that they often see in the media. You started to see kind of the gears turning of, 'Okay, I drive by that field and for the last 10 years, as long as I can remember, it's always been grain corn. That's really not the best practice.'

Because she also farms with her husband, Mrs. B was able to regularly connect concepts from the course to agricultural practices utilized on farms surrounding the local community. As a result, students were more regularly exposed to both the demand and supply-side considerations relevant to the course in a manner that was contextualized by local practices. This provided opportunities for students to make connections between the course content and familiar examples in their local rural landscapes. This aligned with Mrs. B's overall goal of expanding students' use of evidence and system models to support more sustainable decisions in agricultural contexts.

Table 12 - Summary of Situated Learning via Local Contexts for Group B

Item	Phenomena	DCIs	SEPs	CCCs	Discourse Type
Local Contexts	Agricultural production decisions	LS2.A: Interdependent Ecosystems Relationships LS2.C: Ecosystem Dynamics, Functioning, and Resilience LS4.D: Biodiversity & Humans	Evidence-based Argumentation Constructing Explanations & Designing Solutions	Patterns Cause & Effect Systems & System Models	4) Students incorporate their lived experiences to add context and nuance.

Mrs. B also used field trips and guest speakers to illustrate connections between the curriculum and its local relevance to ecosystems and agricultural production. When feasible, students also went to habitats on the school campus for Day 3 investigations. Group B focus noted that this was particularly impactful for them:

> Participant: Yes, we went outside on our campus and they had us look at how we're polluting. You can see a construction, and they were destroying the--
> Participant: We used to have some marshland behind our school.
> Participant: Yes, that's what I was--
> Participant: They recently destroyed that so that it wouldn't be wet and inconvenient for gym classes. We went out there and we looked at it, and I was thinking about the little ecosystem that used to be there and all those species that now were no longer there and how much we killed the biodiversity. I don't know. I got really upset. I felt a connection to the species there. I'm a little odd, so that might have just been me. [chuckles] It was a moment.
> Interviewer: It sounds like you're still a little affected by it?
> Participant: Yes, I'm really upset that they did that.

Analysis comments. Students in Group B's class missed valuable opportunities for framing and transfer if they did not have community-based opportunities through their SAEs. These experiences could have provided students with exposure to contexts in which the course content could be applied to production and stewardship settings.

However, many students already had experiences similar to this. Furthermore, students in Group B's class had a key advantage for framing during implementation through their instructor's experiences and capacity for local contextualization. As both a teacher and a farmer, Mrs. B could more readily describe connections between ecological course content and production considerations. Additionally, Mrs. B readily utilized local references that would be familiar to students as contexts to consider the course content from consumption, production, and stewardship perspectives.

Finally, the use of the Day 5 discourse prompts provided a key opportunity for students for transfer, framing, and discourse. By breaking students into groups based on their backgrounds and career interests, and by having them discuss and present their ideas about connections between the course content and decisions in these contexts, Group B gained valuable preparation for the kinds of scenarios they would encounter during their interviews.

Patterns of student engagement. Mrs. B's students had varying opportunities to express their ideas and collaborate to develop more sophisticated explanations depending on their capabilities. She implemented highly scaffolded implementation for lower performing students. Students had more opportunities for group discourse in sections with higher-performing students: "They're able to go through it on their own, take notes, jot down some of their ideas to the group discussion questions, and then we all come back together as a group."

While Mrs. B's quiz review also often prompted one-dimensional performances from students, she provided more opportunities for three-dimensional engagement and student-driven discourse during investigations and quizzes. Students could collaborate within their small groups to compare and revise their ideas to achieve more sophisticated responses. This enabled them to "feed off of each other and learn from each other."

Similarly, Mrs. B provided additional time after investigations for students to present and revise their ideas. Finally, Mrs. B often implemented an 'agree or disagree and why' discussion with students in response to applications of content that emerged in documentaries, discussions about local practices, and other contextualized settings.

Perceived Successes & Challenges. In comparison to more traditional AFNR courses, she argued that she preferred three-dimensional science learning because “kids got more out of it, and in that way, they would have a better baseline” for making informed decisions. In particular, she valued the systems-based approach and felt that this was key for students to understand “why we can’t do just whatever we want as a farmer.”

Mrs. B noted that in the first weeks of the semester, students’ answers to group quiz questions had “improved significantly.” When I asked her to elaborate, she alluded to three-dimensional outcomes in which students applied what they learned to similar personal contexts:

> “What I saw on the biodiversity and ecosystem quiz was their grasp on the human-managed ecosystems and recognizing 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. Even so much as their lawn. I had one student that had commented that they weren't going to try to kill all the dandelions in the yard this year. They were going to tell their parents that it's because they were maximizing biodiversity.”

Mrs. B also felt that the curriculum was effective for a wide variety of student abilities. She stated that “even students that have some of the lower reading comprehension and things like that, they’re doing really well.” She attributed this in part to the inherent emphasis in the curriculum on “group-based discussion”:

> “[The special education teachers] were kind of concerned that it was going to impact some of the lower achievers that they typically tend to put in the class and it hasn’t. It has been kind of quite the opposite because they’re willing to put in the time and put forth the effort... They’re succeeding...students are having better discussions.”

Mrs. B’s approach to implementation in Year 1 prepared Group B focus students for their interview performances in multiple ways. First, Mrs. B’s instruction emphasized a mixture of individual writing, group discourse, and whole-class discussion. In these settings, students had ongoing opportunities to collaborate within their groups to develop, revise, and improve their explanations and solutions in a manner that supported increasing sophistication. Second, Mrs. B's use of local authentic contexts and discussion prompts that explicitly connected the curricular content to career decisions enabled students to continuously gain exposure to the full array of demand and supply-side considerations needed for their interview performances. This collection of strategies not only prepared students to work effectively within their groups but also provided opportunities to frame their understanding of food production through the lens of sustainable interactions between cultivated fields and adjacent habitats.

Group C – Absence of Group Discourse & Personal Engagement

School Setting and Teacher's Background. Group C (Year 2) also attended Shoehaven High School and were again taught by Mrs. B. This was now Mrs. B's sixth year of teaching, and her second at this school. However, students in the second year experienced a very different learning environment in comparison to Group B due to COVID-19. Students had the option of either alternating daily between remote and in-person attendance or could attend exclusively via remote learning. As a result, student groups were generally comprised of both in-person and remote-learning students.

The small size of Mrs. B's classroom ("I had maternity horse stalls that were bigger than my classroom") in combination with distancing requirements meant that verbal group discussion was nearly impossible. Most group work in this year consisted of a 'divide and conquer' approach. Even for students who were attending in person, their interactions with other students primarily occurred in individualized online spaces without interactive discourse. Furthermore, fewer students in the class had an agricultural background compared to the previous year. This changed the nature of group interactions and whole class discussion, and Mrs. B found it more challenging to relate the curricular content to relevant local examples.

Mrs. B reported less variation in student abilities in Year 2, enabling her to cover the curricular content more quickly: “Surprisingly, we made through more content than last year.” She noted that COVID-19 resulted in changing priorities that partially enabled this outcome:

> I think the change in not having kids do full-blown notes for every unit really made a difference … Kids weren't spending so much time on writing necessarily, and I know that some kids did better with being able to have digital documents versus handwriting.

Introduction to the Units. I remotely observed Mrs. B’s classes throughout Year 2, including her implementation of the Biodiversity and Ecosystems unit. Students began each unit by accessing a Google digital notebook Mrs. B created directly from the FACTS curriculum materials. In contrast to the previous year, students in the second year experienced instruction that was much more teacher driven. This is evident in the following exchange:

> T - So, biodiversity in ecosystems, what do you already know? It could be from 3rd grade science. I will tell your teacher if you don’t remember [laughs].
> [wait time]
> T - Are biodiversity and ecosystems connected? (S’s: yes) How?
> S’s: Science
> T: Elaborate on that. What do you mean?
> S: Interactions between species and non-living resources.
> T: What are examples of that?
> S’s: Rocks, water, air, my grandma [laughter]
> T: You will explain in this unit how biodiversity relates to ecosystem function and resilience. What do you think this means?
> S: How durable something is?
> T: What else?
> S: The amount of immunity something has to a certain element.
> T: If I said you were resilient students, what does that mean?
> S: Immune to learning?
> S: We can adapt to change?
> T: So can ecosystems be resilient?
> S’s: Yes

Students then individually reviewed the unit's driving questions and ranked their comfort in answering each question. Students then watched the unit's introductory video. At the start of the school year, I created a series of short videos (~3 minutes apiece) for each weekly unit support teachers as they responded to challenges created by COVID-19[1]. These videos introduced the Day 1 anchoring phenomena and driving questions, summarized the Day 2 core ideas, and clarified the conceptual models prior to the Day 3 investigation. Mrs. B embedded the videos for each unit in the digital notebook, and students watched the videos individually while wearing headphones.

The curriculum prompts students to work in groups to address the driving questions after watching the video. However, Mrs. B acknowledged that in Year 2, group work was a "disaster" due to COVID-19. This concerned Mrs. B because previously she had had "great discussions" among her groups and felt it would be far more difficult to "pull those conclusions and make those connections without the discussion component." As a result, students in the second year mostly experienced "full class discussion and not necessarily small group discussions."

This change had ramifications for learning outcomes. The student connections between content and their personal lives happened far less often than it did in Year 1. Mrs. B described a particular scenario that emerged during a prior unit to illustrate her point:

> We were talking about species and why there are so many more plants than there are animals and a student asked, "What would happen if you had more animals and plants?" Instead of me having to answer, other students jumped in, and then it translated farther into, 'Is it hunting season here? Why do they have certain hunting tag limits?' They asked whether we would learn about that in the future unit. When they're able to have discussions, they're making those connections. I just don't know how to include everybody in that because that was just an in-person learner discussion without any feedback from students at home.

[1] While there were introductory videos for Day 2 of each unit in the original version of the curriculum, these consisted of relevant YouTube videos that were not explicitly connected to the curriculum.

Without the opportunity for group discourse, Mrs. B felt it was much harder to make the curriculum relevant to individual students' backgrounds and future careers. Furthermore, she struggled to help students identify their initial ideas and see relationships across units during the Day 1 activities.

Students concluded the Day 1 activities with the Data Dives on tabletop ecosystems. However, due to the constraints from COVID-19, it was not feasible for each group to create their own ecosystem, and group discourse was unlikely to be effective. Instead, students experienced a modified approach:

> I had them each come up to me at a table where I was making them. As I was adding the ingredients into their glass jars, I would ask them, "All right, I'm adding phytoplankton. What is phytoplankton in going to be in this ecosystem? Is it a producer or a consumer?"

While this shifted the collaborative sensemaking in small groups to more of a teacher-directed approach, Mrs. B attempted to maintain some opportunities for students to express ideas about the system models and make sense of the anchoring phenomena.

Table 13 - Summary of Introduction to Units for Group C

Item	Phenomena	DCIs	SEPs	CCCs	Discourse Type
Tabletop Ecosystems Data Dive	Algae & brine shrimp ecosystems	LS2.A: Interdependent Ecosystems Relationships LS2.C: Ecosystem Dynamics, Functioning, and Resilience	Asking Questions/ Defining Problems Developing & Using Models	Cause & Effect Systems & System Models	3) Students use valid evidence & models to support their claims.

Analysis comments. Students in Group C's class had much more limited opportunities for framing transfer, and discourse during Day 1 in comparison what students received in Group A and B's classes. First, fewer students had an agricultural background in comparison to Group B, which limited the number of relevant examples Mrs. B could use to contextualize the content from production perspectives. Second, the absence of group discourse limited opportunities for students to link their personal experiences to the course content, and virtually eliminated opportunities for students to collaboratively develop more sophisticated responses.

Unit Implementation. Mrs. B continued to struggle to provide opportunities for group discourse and personal connections throughout the remaining components of the weekly units. In Year 1, students were able to work in small groups and use the curriculum's accompanying PowerPoints to revise their responses to the driving questions on Day 2. Students still worked in small groups in Year 2 to address these questions. However, students were now dividing up the questions among themselves and answering them individually in a shared document instead of collaborating to develop more sophisticated answers.

Table 14 - Summary of Unit Implementation for Group C

Item	Phenomena	DCIs	SEPs	CCCs	Discourse Type
Biodiversity & Ecosystems Unit Core Concepts	Biodiversity, ecosystem services, & resilience Human-managed ecosystems	LS2.A: Interdependent Ecosystems Relationships LS2.C: Ecosystem Dynamics, Functioning, and Resilience LS4.D: Biodiversity & Humans	Developing & Using Models Constructing Explanations/ Designing	Cause & Effect Systems & System Models	5) Students align their responses with scholarly & professional norms & language.

In lieu of group work, Mrs. B used whole-class discussion as an opportunity for students to revise their responses in their digital notebooks. She regularly revoiced, compared, and critiqued ideas expressed by students, but struggled to maintain the same level of engagement as the previous year. This is evident in the following exchange:

> T: Now let's do a brief recap. [crosstalk]. I need everybody on the same page. For whatever reason, it's tougher today. We talked through ecological fragility and resilience last class. I want to go back. [crosstalk]. We are explaining the 10% rule. Why do

> sunnier, warmer, wetter environments have more biodiversity than areas that are cloudier, colder, and drier? Anybody want to jump on that?
> S: Sunnier, warmer, wetter means that plants can perform photosynthesis better than areas that are cloudier, colder, and drier. So there is more variety of plants, and they draw in more animals. Transfer of energy is so great that… [pause]
> T: Anyone want to add on to that?
> S: The transfer of energy would be higher, right?
> S: Yeah, that's what I was trying to… [student interrupts]
> T: Sorry, can you repeat what you said?
> S: There is more transfer of energy because there are more plants to photosynthesize and there can support more animals [inaudible, crosstalk]
> T: Which allows for more what?
> S's: Biomass
> T: Yeah you got it. That's what we're going to start moving towards more. More biomass can support more organisms. We will also look at biodiversity and see how that fits in. We looked at biomass last week. Now we're moving on more towards biodiversity.

Most of discourse was limited to the teacher and a handful of in-person students. It was very difficult for remote students to engage in a meaningful way or even clearly understand classroom conversations. As Mrs. B explained in an email: "Interaction and dialogue among students has been markedly decreased this year with students being in the different locations."

To mitigate these effects, Mrs. B created an additional document which she called TQE (Thoughts, Questions, and Epiphanies). Mrs. B explained her motivation for this in that same email:

> Some students were finding difficulty in previous units with the lack of dialogue and discussion to move from their thoughts/questions to making real world connections and importance of the concepts. I noticed students merely taking notes on the discussion questions posted throughout the unit and I wanted them to move beyond just merely taking notes and begin making the connections to sustainability.

Mrs. B assigned two of the driving questions to each student group. She then required students to develop responses to these questions and present them to the class. She insisted that students should be "listening to your classmates because you are responsible for all of this information, not just the questions you answered. You can build off each other."

Mrs. B used the TQE discussions to connect core ideas across the weekly unit content, including the Day 3 investigations. For example, she had students use their revised TQE responses to improve their responses to the Meadow Simulation Investigation on Day 3. Unlike her students from the previous year, students now completed the simulation and accompanying questions on an individual basis. To provide opportunities for students to challenge and revise their ideas, students presented their ideas during a subsequent whole class discussion: "There are no textbook answers to these. I just want you to jot down your thoughts in response to these."

Table 15 - Summary of Meadow Simulation Investigation for Group C

Item	Phenomena	DCIs	SEPs	CCCs	Discourse Type
Meadow Simulation	How many foxes can a meadow support?	LS2.A: Interdependent Ecosystems Relationships LS2.C: Ecosystem Dynamics, Functioning, and Resilience	Developing & Using Models Evidence-based Argumentation Constructing Explanations & Designing Solutions	Patterns Cause & Effect Systems & System Models	3) Students use valid evidence & models to support their claims. 5) Students align their responses with scholarly & professional norms & language.

Mrs. B also attempted to use whole-class discussion and the TQE document to support more sophisticated reasoning. For example, Mrs. B pushed students to reason more deeply about trophic levels beyond just food webs to address concepts such as biomass, biodiversity, and resilience:

> T: That leads us to the 10% rule. Somebody from home, if a disease were to occur and reduce grass by 75%, what would happen to other species?
> S: The rabbits would die off because they would have less food and then the foxes would die off.
> T: How can we explain this beyond just food? What else is not available?
> S: Energy and biomass
> T: Right. If we had more species of grass, rabbits, and foxes, would our biodiversity increase?

S: Yeah
T: So would it be more or less resilient?
S: More
T: Would we have more or less ecosystem services?
S: More

This type of exchange was a common occurrence throughout the year. While the TQE document seems to have improved classroom discourse, it did not support three-dimensional performances to the same extent as the previous year. Mrs. B acknowledged this herself: “The TQE is okay; it's still not perfect. There are still some kids that are using it as it's intended and others that are still just throwing information in there, just to say that it's done.”

Analysis comments. Again, students in Group C’s class had much more limited opportunities for framing transfer, and discourse during the implementation phase (Days 2-3). Most notably, the absence of outdoor investigations eliminated a key opportunity for personal engagement with phenomena. As such, students had very little opportunity to transfer ideas and practices from the curriculum to real-world systems. Furthermore, students had fewer opportunities for framing from non-consumer standpoints. Finally, the absence of group discourse eliminated key opportunities for students to collaborate to refine their ideas and limited occasions in which to apply disciplinary language and system models. While Mrs. B attempted to mitigate these losses through the TQE document, she observed that this had limited success.

Unit Conclusion. Mrs. B implemented the review and assessments in similar ways as previous years. Students were allowed to use a 3x5 notecard and the review consisted largely of individualized performances. She also provided brief *Gimkit* review sessions for the class. Later in the semester, Mrs. B implemented a technique “where students that are on camera and students that are in-person have either colored or numbered cards to hold up when they want to add on to what somebody else is saying or make a point." Her hope was that this would "get more of our at-home learners engaged."

A key difference between Year 1 and 2 was that students were now completing both the multiple choice and short answer questions individually. Mrs. B felt that Year 1 students had become more skilled at "bouncing ideas off of each other to make [connections to] real world scenarios," enabling them "to feed off of each other and learn from each other." In contrast, the more individualized approach to assessments in Year 2 resulted in "more of a focus on making sure that they got the right answer."

Analysis comments. For Groups A and B, the review and assessments provided valuable opportunities for framing, transfer, and discourse. While Group C continued to have some opportunities to frame their responses from the perspectives of producers, and to transfer ideas and practices from the course to authentic considerations, they lacked the valuable group discourse that accompanied these occasions. This not only limited Group C's preparation for the kinds of tasks inherent in the interview setting but also limited the extent to which their assessments enhanced their capacities for framing and transfer.

Table 16 - Summary of Unit Conclusion for Group C

Item	Phenomena	DCIs	SEPs	CCCs	Discourse Type
Biodiversity & Ecosystems Review & Assessment	Biodiversity, ecosystem services, & resilience Human-managed ecosystems	LS2.A: Interdependent Ecosystems Relationships LS2.C: Ecosystem Dynamics, Functioning, and Resilience LS4.D: Biodiversity & Humans	Developing & Using Models Evidence-based Argumentation Constructing Explanations & Designing Solutions	Patterns Cause & Effect Systems & System Models	3) Students use valid evidence & models to support their claims. 5) Students align their responses with scholarly & professional norms & language.

Situated Learning. While Mrs. B had intended for her students to each have an SAE during Year 2, this was not feasible due to potential liability for the schools during COVID-19. Similarly, field trips and outdoor labs were also not feasible due to most students attending remotely at any given time. Mrs. B was also unable to successfully arrange virtual guest speakers. As a result, students in Group C's class had essentially no formal opportunities for situated learning during this school year.

Mrs. B continued to contextualize course content using local examples that students would find personally relevant. However, she acknowledged that this was more challenging given that her students had comparatively less background in agricultural production. Furthermore, the absence of group discussion, the difficulties in supporting whole-class discourse, and the shortened instructional time created additional barriers for illuminating these connections to authentic local contexts.

Analysis comments. Students in Group C's class had very few opportunities to improve in their capacities for framing, transfer, and discourse during their Day 5 activities. Without SAEs (or similar opportunities), students had almost no personal engagement with phenomena in the local community through their course participation. Due to the absence of group discourse, students were largely unable to take part in discussions about how ideas and practices from the course transferred to decisions they could make as adults.

Patterns of Student Engagement. COVID-19 resulted in significant changes to student engagement between Mrs. B's classes in Year 1 and Year 2. In Year 1, Mrs. B initially struggled to support a diverse range of learners, but over time developed a series of effective strategies to support productive sensemaking and discourse primarily through group work. In Year 2, Mrs. B was unable to utilize this option, and had to develop alternative strategies for sensemaking and reasoning through individual writing and whole class discourse.

To facilitate these changes, Mrs. B increased individual student accountability for the course content:

> This year, I've definitely put more on student responsibility. I'm making them responsible for going through some of the aspects [by themselves]. It wasn't necessarily a flipped classroom, but saying, we're not going to spend three days on the PowerPoint like you might in a lecture-based science course, and letting them swim or drown in the data dives to make conclusions.

These alternative strategies resulted in mixed outcomes that to some extent varied from student to student. Some students successfully used opportunities like the digital notebooks, TQE documents, and whole-class discussions to develop sophisticated performances that incorporated system models and disciplinary language. Other students were less engaged in whole-class discussions and/or their writing focused more on getting 'right answers' than achieving three-dimensional engagement with phenomena. Similarly, Mrs. B had concerns about the extent to which her instruction supported productive engagement because "students that are at a computer just aren't really speaking out loud to anybody else."

Perceived Successes & Challenges. Despite challenges from COVID-19, Mrs. B felt that she had more successful classroom outcomes in Year 2 in comparison to Year 1:

> I'd say it's a lot better this year. I see students making more connections and I don't have nearly as wide of a grade gap, as far as looking at the assessment numbers as well. I see them definitely understanding the whole full ideas and not just bits and pieces of just enough to skate along.

Mrs. B felt that this was due to several factors. She felt more comfortable teaching the curriculum in the second year and was better prepared to anticipate where students would struggle. She also attributed some improvements to the revisions to the Matter and Energy units which enabled deeper comprehension about cellular processes which improved students' capacities to reason across systems and scales. She also felt that the addition of the unit videos helped to mitigate the challenges faced by students who attended remotely.

Mrs. B acknowledged that the absence of situated learning limited students' capacities to relate the content to real-world decisions outside of the classroom: "They're still making good connections, but I think having the community-based learning day or a work-based learning day would take it a step further." She acknowledged that while her students' classroom performances had improved in the second year, "they're struggling in actually explaining those concepts to other people."

Mrs. B also expressed concern that she was less capable of determining "whether or not they have other specific interests that relate to the course." Like Mrs. E, Mrs. B felt that the amount of content made it a "struggle a little bit to get through everything adequately." She argued that unless the course was expanded to a full year, students would not have opportunities to sufficiently identify relevant connections between the course content and their personal lives.

Mrs. B's implementation during Year 2 likely had mixed implications for student performances during their focus group interviews. While Mrs. B felt that these students' classroom performances were stronger in comparison to Year 1, she also had concerns about students' capacities to transfer their knowledge and practice from the course to authentic scenarios (which would be necessary for successful interview performances). Second, students who were fully remote struggled to achieve the same level of engagement and in general, students could focus more on getting the "right answers" than on engaging in productive three-dimensional engagement with the phenomena. Finally, students in Year 2 essentially lacked all opportunities for situated learning (outdoor investigations, SAEs, field trips, guest speakers, etc.). Given that focus students in Groups A and B identified these opportunities as among the most impactful in their experiences with the curriculum, it is highly likely that this also affected Group C's opportunities for productive engagement in the class.

Similarities and Differences Among the Classroom Narratives

Similarities. While each of the three focus groups encountered unique opportunities to learn because of their classroom experiences, there were key similarities across all three classrooms. In each case, the case study teachers implemented the FACTS curriculum in the order and general way it was designed. As such, each classroom covered generally the same overall content (with slight differences in the amount of content covered).

Similarly, none of the classes were able to reach the final section of units (individual and societal sustainability) within the allotted time. This is in large part due both teachers prioritizing productive classroom discourse over 'covering content' – i.e., both teachers valued eliciting and improving students' ideas over more procedural displays of knowledge. However, this also resulted in students having less exposure to some key opportunities to connect the course content to authentic decisions that would be relevant to both their personal lives and surrounding communities.

Finally, both teachers explicitly valued their instruction as opportunities to facilitate systematic reasoning and informed decision-making. They prioritized the end goal of enabling students to construct increasingly sophisticated explanations and develop solutions in lieu of rote memorization of facts and processes. Both teachers regularly used strategies such as the Nine Talk Moves to support productive classroom discourse to generate questions, elicit ideas, and support evidence-based argumentation.

Impact on Student Performances. These similarities across the three classrooms had implications for student performances during their focus group interviews. In comparison to more didactic approaches to agriculture and science learning, students in these courses would have had comparatively greater opportunities to be productively engaged in addressing questions and problems in a manner aligned to the norms and realities of the discipline.

For example, in lieu of memorizing facts and definitions, students in these classes engaged in activities that emphasized making sense of phenomenon, identifying problems, and designing solutions. Similarly, the first interview question ("What do you perceive as threats to future food production?") requires that students engage in forms of reasoning and sense-making that go beyond reciting memorized information. By having regular opportunities to express their ideas, identify supporting logic and evidence, and justify their conclusions through class participation, students in all three focus groups were better positioned to respond to the interview questions in comparison to their initial interview.

Furthermore, the curriculum emphasized management of adjacent habitats and the interactions between these habitats and cropland. These considerations are key for moving students along a trajectory from their initial focus on consumption and demand towards the mechanisms that determine crop productivity and system sustainability. Given that all three focus groups initially relied on good/bad reasoning in their initial interviews to address considerations beyond demand, their opportunities to reason more deeply about the supply-side considerations would better enable them to achieve the target performances during their later interviews.

Differences. Three key differences emerged across the three classrooms. These differences pertained to opportunities for students to improve their capacities for framing and transfer and engage in group discourse.

Group A.

Framing. Students in Group A's class had multiple opportunities to frame their understanding of rural landscapes and food production from both producer and consumer perspectives. These experiences would have provided additional preparation for focus students to achieve the interview target performances beyond the opportunities designed in the FACTS curriculum. First, Group A's class managed the recycling program for the school. They devoted half of a class each week to emptying all of the school's recycling bins. The students reported that these experiences helped them "realize that you can make a difference" and resulted in changes to their own personal decisions.

Group A's class also felt that their field trip to a university agricultural research facility was impactful for understanding consumer and producer impacts on ecosystem function. They felt that this opportunity provided "an interesting perspective, like real life." However, Group A's descriptions of the trip suggest they partly viewed it as an opportunity to gain exposure to potential career paths in agriculture. For example, one student noted that the trip helped him realize that "there's so many different specific jobs that you can actually make really good money from when you go into that field."

Finally, Group A's class completed career portfolio components that were included as part of the curriculum (such as career exploration, resumes, and cover letters) and were required to obtain 15 hours or more of community-based career experiences (SAEs). They also kept records of their experiences and wrote reflections. These career experiences were largely treated as a separate component from the course content. Students did not take part in the Day 5 discourse prompts meant to help them identify explicit connections between the curricular content and decisions they would make as producers and/or consumers. As such, Group A reported that these experiences did not change how they viewed or understood the course content:

> Participant 1: I want to be in marketing...So that's what I job shadowed. It didn't really affect me in that way.
> Facilitator: You didn't really see a connection?
> Participant 1: No.

Group A's lived experiences positioned them more as consumers, and their initial interview responses reflect this. They were able to gain some exposure to production considerations through the course content and from their field trip. However, their career and community experiences were framed more as career exploration, and they were unable to take part in opportunities that were designed to help them explicitly consider questions about agricultural sustainability and resource management from multiple perspectives. While Group A had repeated opportunities to reason about agricultural production using ecological system models, they continued to do so predominantly from the perspectives of consumers. Their limited exposure to supply-side considerations limited their capacity to fully achieve the interview target performances.

Transfer. Students in Group A's class had repeated opportunities to investigate anchoring phenomena from the course in local habitats and other authentic settings. This provided valuable opportunities to apply ecological knowledge and practice from the FACTS curriculum to real-world systems.

For example, Group A's class worked in small groups to identify evidence of disturbances (e.g., habitat degradation, invasive species, pollution, etc.) on their school's campus. During the following week, students worked in groups to identify specific phenomena related to habitat degradation (e.g., fragmentation, edge vs. interior habitat, corridors, etc.). In each case, students had to work in groups to collect evidence, form a conclusion, and defend their ideas in whole-class discussion. Group A reported this to be one of their most impactful experiences:

> You just think about fragmentation and that sort of thing more and biodiversity loss. Like when you watch stuff on the news or whatever kind of media you're consuming, I just pick up on the different scientific terms that I'd had no idea what they were before and things just sort of make more sense now because I have that better understanding. Like I said earlier, it makes me want to go learn more about it.

Group A's experiences suggest that these opportunities to transfer knowledge and practice from the classroom setting to real-world systems enable deeper reasoning about that content. Furthermore, it enabled them to apply concepts from the course to novel scenarios to develop explanations and solutions. These experiences reflected the kinds of tasks that Group A would encounter during their interviews and would have provided key preparation for students to achieve the target performances.

Discourse. Of the three focus groups, Group A had the most frequent opportunities to engage in meaningful group discourse during their classroom instruction. Students in Group A's class would have encountered opportunities for group discourse nearly every day. Furthermore, they were prompted to express their ideas and engage in evidence-based argumentation during these opportunities.

For example, students in Group A's class began each weekly unit by considering data from a case study, identifying patterns, and defending the conclusions they developed as a group during the subsequent whole-class discourse. During this time, they also developed explanatory models that they continuously revised over the week as they gained more information about the unit's anchoring phenomena. Prior to the unit assessments, students in this class worked in teams to develop answers to the unit's driving questions and critiqued other students' stances ("why you refute, dispute, agree with or need to add on something").

These opportunities reflected the kinds of performances Group A would encounter during their focus group interviews. Between their initial and final interview, Group A increasingly collaborated to develop more sophisticated responses to the interview questions. They regularly completed each other's sentences and often respectfully challenged each other's stances. Through their capacities for collaboration, Group A students were able to improve their reasoning and explanations by identifying opportunities to include disciplinary language, frame their arguments using system models, and connect their ideas to authentic contexts from the class and their personal lives.

Group B.

Framing. Group B's class had the most frequent and productive opportunities to analyze rural landscapes and food production through decisions made by both producers and consumers. This was partly attributable to Group B's extensive personal connections to production agriculture. Furthermore, these students were able to identify explicit connections between the course content and decisions made in both consumer and producer contexts through classroom discourse.

The most notable opportunity of this kind was the discourse prompts in the Day 5 Career and Community Connections activities. Students were broken into groups based on their career interests and guided in identifying how the content from the weekly units pertained to decisions they would make in their potential occupations. Students shared their ideas in subsequent whole class discourse, allowing students to frame these considerations from both consumer and producer perspectives.

In addition, students in Group B's class were regularly guided in identifying connections between the course phenomena and decisions made by local agricultural professionals (including their instructor). For example, students observed that a field near their school had been planted in corn year after year: “I drive by that field and for the last 10 years, as long as I can remember, it's always been grain corn. That's really not the best practice.” These authentic contexts provided key opportunities to reason about the ramifications of production decisions on biodiversity, ecosystem services, and resilience.

These experiences would have provided valuable preparation for Group B to achieve the interview target performances in their subsequent interviews. Specifically, Group B would have been better positioned to address factors related to demand, reason about system models relevant to managing habitats in rural landscapes, and develop strategies for crop management (particularly conventional vs. conservation methods). Their movement along this trajectory would have more fully prepared them to explain the mechanisms through which these factors affect crop productivity and system sustainability.

Transfer. Like Group A’s class, students in Group B’s class had opportunities to investigate anchoring phenomena in habitats on their school’s campus. These were valuable opportunities to transfer knowledge and practice from the classroom setting to real-world systems. Group B also noted the impact that these opportunities had on their motivation and emotional investment in the course content. For example, they became aware that the school had intentionally removed a wetland on its campus during these opportunities:

> Participant: We used to have some marshland behind our school. They recently destroyed that so that it wouldn't be wet and inconvenient for gym classes. We went out there and we looked at it, and I was thinking about the little ecosystem that used to be there and all those species that now were no longer there and how much we killed the biodiversity. I don't know. I got really upset. I felt a connection to the species there. I'm a little odd, so that might have just been me. [chuckles] It was a moment.
> Interviewer: It sounds like you're still a little affected by it?
> Participant: Yes, I'm really upset that they did that.

For Group B, these outdoor investigations provided a level of connection that wasn't feasible through classroom instruction alone, and they reported having a much deeper interest in the subject matter which included an emotional investment. Furthermore, they were better able to frame their experiences by transferring system models and disciplinary language from the course to this real-world example as a result.

Students in Group B's class also had additional opportunities to apply curricular knowledge and practice to production systems, particularly the Day 5 group and class discussions. Students identified decisions that professionals in these career areas would make and used ideas and practices from the course to identify relevant connections.

Furthermore, students in this class had opportunities to meet with local professionals in person to gain insights and ask questions. For example, these students had the opportunity to meet with a university extension educator and identify relationships between the course content and horticultural production. As their instructor observed, the extension educator "was surprised that there were high school students that were making that connection between [regenerative agriculture and local biodiversity]."

Finally, it should be noted that students in Group B's class may have gained additional preparation from the experiences and funds of knowledge of their instruction. In addition to teaching, Mrs. B also farmed with her husband. Students in her class regularly asked her about the decisions that she and her husband made and how they related to the course content. These conditions provided valuable opportunities for Mrs. B to model how she used ecological system models to reason about production decisions on an actual farm. Their involvement in outdoor investigations, discussions on more informed decisions in their future careers, and interactions with local professionals provided them with interview preparation for transfer beyond that which was originally designed in the FACTS curriculum.

Discourse. Students in Group B's class encountered mixed opportunities to engage in meaningful group discourse during their classroom instruction. While Group A's class engaged in group discourse nearly every day (to an extent that went beyond the initial curricular design), students in Group B's class had more limited opportunities. This was due to modifications implemented by their instructor to accommodate the diverse range of learners in her classroom. However, students in Group B also stayed together in the same group the entire semester, supporting their capacity to collaborate with each other as they became more comfortable in working together. Additionally, Group B had an additional opportunity to engage in group discourse during their Day 5 discussions.

Overall, both Group A and Group B demonstrated similar improvements between their initial and final interviews, such as increased frequency in which they enhanced each other's responses through additions of disciplinary language and system models, as well as respectfully challenging some assertions and providing examples from authentic contexts.

Group C.

Framing. Group C had far more limited opportunities to analyze decisions about food production from the perspectives of both producers and consumers in comparison to Groups A and B. This was largely due to changes that emerged in response to COVID-19. Students in Group C's class did not have the option of attending field trips and were prohibited from having SAE experiences. Additionally, their instructor was unable to successfully make arrangements for remote presentations by guest speakers.

Group C did have some exposure to supply-side factors through their instructor's accounts of decisions on her own farm. However, unlike Group B, students in Group C were unable to take part in group discourse, making the Day 5 group discussions about career-based decision making infeasible. While their instructor attempted to recreate some of these aspects through individual writing and class discussion, Group C would have had fewer explicit opportunities to identify connections between the curricular content and decisions made by both producers and consumers.

Furthermore, Group C was like Group A in that their lived experiences positioned them more as consumers. Unlike Group A, they lacked opportunities to gain exposure to production considerations through opportunities like field trips. Without access to SAEs, they lacked community-based exposure to real-world systems pertaining to agricultural sustainability and resource management. With some exceptions, Group C's exposure to the course content predominantly pertained to the perspectives of consumers. Their minimal exposure to production decisions limited their capacity to fully achieve the interview target performances.

Transfer. Due to COVID-19, students in Group C's class were unable to take part in outdoor investigations situated in local habitats. They also lacked opportunities to engage in career-based group discussions or to engage with guest speakers with expertise in relevant fields. As such, Group C had very few opportunities to transfer knowledge and practice from the classroom setting to real-world systems. This affected not only their engagement with the content but also their preparation to apply concepts from the course to novel scenarios to develop explanations and solutions. This almost certainly limited their preparation to achieve the interview target performances and had ramifications for their motivation and engagement.

Unsurprisingly, Group C reported very different perceptions of the class in comparison to Groups A and B during their subsequent interviews. Group A spoke at length about their experiences with recycling and the field trip, and Group B provided passionate responses about local habitats and the ramifications of specific production options. However, Group C's interviews lacked the same level of personal connection to the course content. While they expressed enjoyment in the class, they did not think that it changed their perceptions of the course content.

Group C's experiences provided very limited preparation for the type of engagement they would encounter during their subsequent focus group interviews, and had the least preparation to apply ideas and practices from the course to real-world systems given their very limited engagement with phenomena.

Discourse. While both Groups A and B had regular opportunities for group discourse, this was not an option for Group C. The challenges presented by remote learning and social distancing among in-person students made group discourse a "disaster". Group C explicitly acknowledged the challenges the resulted from the absence of these opportunities:

> Interviewer: How does that compare to like what you have had face to face in the classroom?
> Male Participant: It's a lot more difficult.
> Female Participant 2: It's definitely a lot more difficult, because we can't see each other face to face. I feel like it's harder to explain in detail when you're not showing people like, "This is how you should do it. This is how I feel like you should do it."
> Male Participant: I find it difficult to discuss over video chat.
> Interviewer: It sounds like you're saying it may be harder to convey your thoughts or ideas when you're not face to face, than when you were in person?
> All: Yes

As a result of these circumstances, students in Group C primarily engaged with the course content and with each other through individual writing and through whole-class discourse. Often their use of the curriculum more resembled worksheet completion than opportunities for three-dimensional engagement with the phenomena. Even when they started using the TQE document to engage in deeper reasoning about phenomena, they were primarily working independently of each other.

The lack of opportunities for group discourse reduced Group A's preparation for the focus group interviews. Group C showed very little improvement in their capacity to develop more sophisticated responses through collaboration. Unlike Groups A and B, Group C's interview responses were primarily individualized, and they were far less likely to expand on their group member's responses. As a result, they struggled more to fluently utilize disciplinary language and system models from the course to communicate their ideas. In combination with their lack of situated learning opportunities (like job shadowing and outdoor labs), Group C was less capable in connecting their ideas to authentic contexts from the class and their personal lives.

Classroom Performances

Due to COVID-19, the hard copies of student work that had been saved for analysis during the 2019-2020 school year were lost. The exception to this were digital copies of Group A and B performances during the midterm exam. While I only have average scores for Group A's class, I do have the written responses for Group B as well as for Group C. This provided a valuable opportunity to compare a consistent sample of Group B and C's work, allowing for a partial comparison of their interview performances with their classroom performances.

Mrs. B felt that overall, students in her second year were "having higher performances than last year." She noted that, "Written responses and oral responses … are light years better" and that students were more frequently "making complete connections." Mrs. B also noted that there was less of a gap between low and high performing students and that overall, students in the second year were "understanding the whole full ideas and not just bits and pieces."

Mrs. B also observed that students in both Group B and C were comparable, and that two of the three students in Group C were "doing extremely well and are the most actively engaged." Her claims are supported through examples of student work. For example, focus students in both Group B and C addressed the following question on their assessments: *Why do ecosystems in warm, wet, sunny areas (like tropical rainforests) have greater amounts of biodiversity, provide larger amounts of ecosystem services, and have greater resilience to disturbances than ecosystems in cold desert regions such as the Antarctic and mountain tops*? The following represent the strongest performances among focus students in each class:

> **Group B Focus Student**: Warm and wet regions have more biodiversity and ecosystem services because the climate is more favorable to producers. When there is more water, sunlight, and warmth available to producers, it increases the amount of photosynthesis, which increase [sic] the amount of biomass production in the producer level. Because of the ten percent rule, the amount of energy and biomass in the next trophic level of consumers increases because they are dependent on the producers. This increases the total biodiversity because more species are able to emerge and survive than they would in a harsh climate. And when there is more biodiversity, there are more ecosystem services available because of the increase in species. Increased biodiversity also increases ecosystem resilience because one particular natural disaster or disease is less likely do [sic] disrupt the whole ecosystem when there are more species that might not be susceptible to the problem.
>
> **Group C Focus Student**: A major factor for why tropical rainforests have more biomass diversity and mass compared to a tundra is, that biomass production is increased in warmer, wetter environments. The 10% rule plays a substantial role in this as well because it states that for every unit of plant biomass consumed, only 10% of that producer is transferred to the consumer, this means that the diversity and size of ecosystems are limited to the above stated requirements. This is why tropical rainforests have more sustainable diversity than a tundra.

In both cases, the students could identify a specific causal mechanism (10% rule) in order to explain why warmer, wetter, and sunnier areas have more biodiversity due to their greater capacity to produce plant biomass, which serves as the basis of all food chains. Both examples also showcase use of disciplinary language and system models to support their arguments. This evidence in combination with the teacher's observations and my own classroom observations suggests that both Group B and Group C focus students were capable of proficient classroom performances.

Final Performances

In the following sections, I will describe the progress each group of focus students made toward achieving the key target performance. I will then discuss similarities and differences between the focus group performances and conclude with an analysis of how classroom performances related to interview performances.

Group A – Group Discourse and Personal Engagement with Limited Perspectives

Group A completed their final interview at the end of the semester shortly before their final exam. In response to the question of what they perceived as the greatest threats to future food production, these students stated that they still had "the same answers" as their previous interviews, and that their opinions hadn't "changed too much." They again suggested that overpopulation and "weather and everything like that" posed the greatest threats. Their initial responses continued to frame the problem around consumer factors as their primary means for making decisions and understanding threats to food production.

Expanded emphasis on ecosystem interactions. I then asked if they considered changes to biodiversity and ecosystem function as a potential threat. One student argued that "biodiversity does help keep the ecosystems stronger, so I think keeping biodiversity high will definitely help," referring to ecosystem resilience. Another group member expanded on this:

Participant 3: Ecosystem resilience would be, say you're building a road through an ecosystem, and it's depending on how strong that ecosystem is, it's how well it reacts to that other--
Participant 2: The outside factors and stuff like that.
Facilitator: It's like a disturbance?
Participant 2: Yes, how strong it is.

I asked why adjacent habitats were important given we "don't normally grow food in forests." One student argued that there was "more to food than just crop production," adding:

Participant 3: ...animals living in those ecosystems, if their ecosystem is depleted then they're probably not going to have as good of a chance of--
Participant 2: Yes, like the documentary we watched about the bees, because bees help pollinate a bunch of different crops that way every single day. A lot of the bee ecosystems are falling apart and they have to bring them in from outside sources.

Students went on to argue that "if there's less biodiversity, we'd probably have to be more interactive with our ecosystem," adding, "because if [ecosystem services are] not naturally happening, then we're going to have to force it to happen." When pressed to elaborate, they stated that losses to biodiversity would require "more time, energy, and money" to replace the subsequent losses in ecosystem services.

Analysis comments. Students in Group A consistently expressed concern about what is happening in adjacent habitats but they rarely connected this to decisions made on farms other than this case. The way they framed this is predominantly from a consumer's perspective (a), namely that technologies related to consumption have ramifications for interactions within adjacent habitats. In terms of transfer, they discussed mechanisms by which changes in adjacent habitats can affect production (b3), but it is notable that this is one of the only times that this was addressed. Furthermore, Group A's discourse demonstrated a capacity to collaborate and build off each other's ideas to develop more sophisticated responses.

Solutions focused on consumption. In the next portion of the interview, I asked what solutions they recommended to address these threats. Their responses continued to reflect a strong emphasis on the demand perspective. For example, Group A initially suggested that reducing food waste among consumers was a key solution: “If I can change the world and say, this is what's going to happen, I would have people buying what they need and not just random foods.” They also argued that consumers need “more effective proteins and stuff like that” (such as lab-grown meats) to mitigate the effects of their consumption. They went on to argue that because “we have so much food that we're throwing it away and wasting it, we're making too much.”

To prompt Group A to consider solutions beyond consumption and demand, I asked if they thought we could keep using the same production and “still be ok in 30 years.” One student argued that due to losses to biodiversity from these methods, “eventually there'll be a straw that breaks the camel's back.” Another student challenged this, arguing, “Then again, we've been doing most of the same practices for a long time and the population increases,” adding, “There's been different problems over time. I feel like we always adapt and overcome.”

This led to a brief but engaged discussion as to whether ecological disturbances necessitated an immediate response to prevent large scale ramifications. Their responses suggested that consumer decisions ultimately mattered more than those of producers:

> ...if a bunch of people decided that they were only going to buy foods from businesses that supported biodiversity and did a whole list of things that would potentially help the environment and there was a bunch of the American population that did it, then the corporations would follow the trends so they could keep making money.

Analysis comments. Students in Group A continued to frame their understanding and decision-making about agricultural sustainability from the perspectives of consumers (a), even when explicitly prompted to consider the same considerations from a production standpoint. Their discussion of the relationships between biodiversity and crop production primarily reflected the use of good/bad heuristics but did not address specific interactions between cropland and adjacent habitats (b3) or causal mechanisms that determine system sustainability (c).

In terms of transfer, students acknowledged ways in which agriculture can be detrimental to biodiversity and ecosystem function (b3). However, their responses in this section are largely devoid of system models from the course such as specific ecosystem services, forms of disturbances, or carrying capacity. While this particular exchange also provided key opportunities to discuss production strategies (b1) and specific options for habitat management (b2), these students did not address these connections. Regarding discourse, students in Group A were actively listening to each other, critiquing each other's ideas, and engaging in meaningful discourse to aid their reasoning about potential solutions.

Applications of course ideas and practices. During their final interview, I added additional questions to the interview protocol that prompted students to address scenarios that included both ecological and agricultural phenomena. These scenarios included identifying patterns in changes to global biodiversity, assessing claims about uses of marginal land in rural landscapes, and designing options to balance tradeoffs in production agriculture. Their responses to these questions alluded to opportunities they had gained through their classroom experiences as well as their ongoing emphasis on consumer decisions.

For example, students were asked to interpret graphed data on species extinction and make predictions about how human activity might relate to the trends they identified. One student immediately identified habitat loss as a key potential factor, and provided a real-world example from current events:

> **Participant 2**: If you look at just something recent like-- oh God, what is his name? The Brazilian president? I can't remember his name?... Jair Bolsonaro?... He approved to tear down a huge swath of the Amazon rainforest and turn it into agricultural lands. That human activity can really affect ecosystems in certain ways, because especially in places

> like the Amazon there are species that are so densely populated that they're in really small spaces. For all we know, there could have been an entire species that was wiped out in just that one chunk of burning forest.

Another student identified “huge amount of carbon emissions that humans are responsible for” as a key factor in the “warming of the ocean,” adding, “it’s destroyed a huge amount of coral reefs, which are in turn home to a bunch of different species of fish and caused them to have to either leave or just die.” Both examples alluded to the system models from the course that addressed causal mechanisms for how human activity can act as ecological disturbances. Habitat loss due to agriculture and ocean acidification are specific examples addressed in the course content. Students in this case also built on these examples by connecting them to current events, which they acknowledged they were now “much more inclined to read” because of their course involvement.

In the next block of questions, students were asked to critique hypothetical statements about food production and explain how they agreed or disagreed with each. In their evaluations, Group A showed clear improvement from their initial interview to consider supply-side factors such as management of rural habitats and interactions between those habitats and adjacent fields. This was particularly evident when one student argued that:

> **Participant 2**: We need some of the marginal land and fencerows and stuff. You can't just go right up to the edge, whatever, because there's going to be runoff and stuff like that.
> **Facilitator**: Okay, so if you get rid of marginal land you have more impact from those fields on ecosystems outside of it?
> **Participant 3**: Yes, and less biodiversity around the fields.

In the final block of questions, students are asked to design solutions for farmers to balance the need for profitable production and maintaining functioning ecosystems outside of areas used for production. Group A quickly acknowledged their perceived limitations in addressing this question:

> **Participant 1**: The ways that they decide to do that if it's good or bad. I don't know how they produce food. I don't know that way, but if it's up to the standards or good ways to do it and bad ways to do it, then I'd want to make sure that they were doing it sustainably.
> **Participant 3**: If you were one of those people who would know a lot more about what you're looking for. I wouldn't really know--
> **Participant 2**: The whole point that I could think to ask is what kind of pesticides they use and then do research on the effects of those things.
> **Participant 1**: Yes, if they use the correct things that are tested.
> **Participant 3**: I'm sure even you know if you did it regularly, you would know what you were looking for all the time. I mean just what they're producing, how they're producing it, how they're distributing it, what they're putting in their crops, look at their equipment, how their fields are set up.

In their responses, Group A position themselves as someone other than "people who would know" about options for sustainable agricultural production. Notably, Group A's classroom learning opportunities in this regard went beyond the curricular design. Through their field trip, they had direct exposure to conservation agriculture methods, and their classmates had acquired funding to implement some of these methods in a field on their school's campus. They also had opportunities to personally investigate some specific conservation methods (e.g., reduced tillage, manure injection, etc.) using potted plants in their greenhouse. Finally, they alluded to the value of marginal lands and fencerows in preventing habitat disturbances during the previous question. However, their responses in this case lack any mention of these considerations. Despite having multiple opportunities for personal engagement with agricultural phenomena, Group A is largely unable to transfer those ideas and practices to their interview performances.

Analysis comments. In their responses to these additional questions, Group A again framed their ideas primarily from the perspectives of consumers (a). In particular, they explicitly acknowledged their inability to suggest improvements to agricultural practices when asked to design solutions.

They also demonstrated limited abilities to transfer ideas and practices from the course to these interview questions. While Group A had direct exposure to conservation agriculture methods beyond the curricular design, they did not link these experiences to their interview performances. They demonstrated an improved capacity to reason beyond factors related to demand and consumption (a) to include the function of adjacent habitats (b2). However, they were largely unable to address specific considerations related to crop production (b1), interactions between cropland and adjacent habitats (b3), and causal mechanisms that affect productivity and sustainability in rural landscapes (c) even when the questions explicitly addressed these considerations.

Group A again demonstrated a capacity to collaborate and build off of each other's ideas in order to develop more sophisticated responses through discourse. However, these interactions also suggest limitations in the extent to which discourse enabled them to reach the interview target performance. This is particularly evident in their responses to the final block of questions, in which their responses seem to confirm their perceived inability to suggest specific improvements to agricultural practices.

Comparison to Initial Interview Performance. Group A demonstrated improvement from their initial interview regarding their capacity for framing, transfer, and discourse. While their first interview responses focused almost exclusively on demand. In their final interview, Group A expanded their framing in their final interview to include ecosystem interactions in adjacent habitats. While they had increased in their capacity to discuss production considerations and their relationships to overall system sustainability, they generally addressed the interview scenarios from the perspectives of "activist consumers." Despite having had more exposure to production than originally designed in the curriculum, they didn't self-identify as "one of those people who would know a lot more."

Students in Group A demonstrated greater improvement in their capacity for transfer between the initial and final interview. At this point, they were able to utilize ecological disciplinary language and system models to respond to authentic contexts and considerations in a manner that was not feasible during their initial interview. This was particularly evident when students were able to interpret data on species extinction, link it to phenomena from the course, and contextualize their responses using real-world examples (such as the Bolsonaro excerpt). Thus, students demonstrated some proficiency in applying ideas related to ecosystem function (b2) to authentic scenarios.

However, these students still demonstrated a limited capacity for transfer when the scenarios pertained to crop production strategies (b1), interactions between cropland and adjacent habitats (b3), and causal mechanisms that affect productivity and sustainability in rural landscapes (c). Despite having greater exposure to these concepts than intended in the curriculum, they perceived themselves as being unable to apply production-based ideas and practices from the course to the same extent as similar ideas about ecological function.

Finally, Group A's discourse patterns had also changed since their first interview. Specifically, students were more regularly collaborating to achieve more sophisticated explanations. At this stage, their responses were still largely comprised of lifeworld language at first (e.g., keep the ecosystems "stronger"); however, through collaboration they were able to incorporate disciplinary terms and real-world examples to enhance and clarify their performance. Students also demonstrated increased engagement by more actively engaging and competing to provide responses in comparison to their initial interview.

Relevance to Classroom Implementation. The patterns of improvement between Group A's initial interview performance and their final interview correlates closely with their classroom opportunities for learning. Specifically, the way Group A experienced opportunities for framing, especially SAEs and the lack of Day 5 discourse, limited their exposure to supply-side considerations through the course. They would have had comparatively greater opportunities to consider the ecological stewardship perspective; however, this would not fully prepare Group A for the kinds of performances needed for the interview questions, which was evident their continued emphasis on demand.

Group A's regular opportunities outdoor investigations provided key preparation for transfer interview performances. These opportunities required students to regularly apply ideas and practices from the classroom to real-world systems and phenomena. While Group A noticeably improved regarding their ability to transfer ideas about ecological interactions to authentic contexts, they demonstrated less improvement in regard to topics like crop management and interactions between cropland and adjacent habitats. This likely reflects their comparatively limited engagement in authentic contexts that were directly relevant to these scenarios. A notable exception to this was their field trip to tour conservation agriculture research. However, even in this case, the students perceived this trip to be as much about career pathways as agricultural production.

Finally, Group A demonstrated continuous improvements in their capacity to develop more sophisticated responses through collaboration. This almost certainly reflects their almost daily opportunities for productive group discourse in a manner that went beyond the curricular design.

Group B – Group Discourse and Personal Engagement from Multiple Perspectives

Group B completed their final interview a few days after their final exam. In their initial interview, these students perceived pollutants from increased consumption as the primary threats to food production. However, in their final interview, Group B changed their primary threats to soil depletion and unsustainable farming practices. They were concerned about nutrient runoff and a lack of crop rotation in conventional agricultural practices. They argued that practices that were adopted to “get a greater output” needed to be “sustainable and eco-friendly and all that jazz.”

Production and stewardship framing. I then asked if they saw biodiversity or ecosystem function as relevant to the question about threats to a sustainable food supply. They responded:

> **Participant**: If there's not a lot of biodiversity, then the ecosystem services, they're lower. Also, globally, if there's less biodiversity and there's less plant mass typically, and with less plants, you can't support as many organisms. That ties into agriculture where if the plants aren't there to keep the planet running smoothly, then we can't farm.
> **Participant**: I feel like it also ties into crop rotation because if you don't have biodiversity in, say, one field, then one plant is going to suck up all the nutrients that it needs and it won't be able to grow well. It can't support as much.
> **Interviewer**: Anything else in biodiversity or ecosystem function?
> **Participant**: The more biodiversity, the more stable the ecosystem is, and the more the ecosystem can support, which increases the ecosystem services. It all ties together.

Their response clearly and succinctly incorporates ecological system models from the course to analyze production systems. They argue that reductions to biodiversity lead to reductions in ecosystem services, resilience, and habitat carrying capacity, which are needed to support agriculture. They also stated that monocultures can lead to nutrient imbalances that can impair field productivity.

Analysis comments. In their final interview, Group B framed their responses to the questions in a very different manner from Group A. Specifically, Group B predominantly framed their responses to the interview questions from a production perspective. This is explicitly evident in responses such as: "…then we can't farm," in contrast with Group A's reference to farmers as "they." In most responses, Group B primarily framed threats in terms of production (b1) and ecological stewardship (b2) roles.

Group B also utilized opportunities to connect classroom ideas and practices to their interview scenarios. They addressed crop production strategies (b1) that reduce disturbances such as runoff in adjacent habitats (b3). They also discussed interactions between fields and adjacent habitats as well as the mechanisms that affect system sustainability (c), particularly the need for ecosystem services and sufficient habitat carrying capacities to support agricultural production.

Additionally, Group B also demonstrated collaborative discourse patterns. They listened to each other's responses and built on each other's ideas. For example, their dialogue about the roles of biodiversity and ecosystem function led to concise but detailed descriptions of interactions between ecological system models and the impact on food production decisions.

Solutions focused on production. In the next portion of the interview, I asked what solutions they recommended to address these threats. Unlike Group A, Group B's proposed solutions focused primarily on production systems. Their responses mostly consisted of conservation agriculture practices. For example, they advocated for reducing tillage because, "If we till the land and there's heavy rainfall, then the soil is just going to run off the field into streams and creeks, rivers" and that this would cause eutrophic "dead zones."

They also repeatedly advocated for crop rotation, having argued that this would lead to more effective nutrient management in the soil. To this they added that "there's tons of best management practices that we can follow to try and make an ecosystem more sustainable," alluding to aspects of the curriculum that specifically addressed conservation agriculture. They also suggested that "making people aware of the problems is a good thing" because this would mean "people are more likely to start putting in place these practices and doing them." They concluded by suggesting that consumers could play a role by supporting "companies that do follow best management practices" because this would increase the implementation of conservation agriculture.

Analysis comments. Here again Group B framed their responses from production and stewardship perspectives (e.g., "we till the land" and "practices that we can follow"). An exception to this occurs briefly when they alluded to potential impact of consumer decisions, but even here they framed the consumers more as "other people" whom they would educate.

Their capacity for transfer is evident in that they explicitly addressed conservation agriculture strategies (b1) and habitat disturbances (b3). They used their discussion of these factors to address the causal mechanism that result in eutrophication of aquatic ecosystems and impair overall system sustainability (c). Finally, Group B continued to use collaborative discourse to build off each other's ideas to develop more sophisticated responses.

Applications of course ideas and practices. Like Group A, this was Group B's first encounter with the new questions that I had added to the interview protocol (changes to global biodiversity, assessing claims about marginal land, and designing options to balance tradeoffs).

The data on species extinctions compared losses of vertebrate species and species of insects. I asked students to make predictions about how the comparatively greater rate of insect extinctions might affect ecosystem services and function. They responded:

> **Participant**: Well, insects play a major role in pollination. Insects are keystone species. If the insects are gone, then the plants aren't going to get pollinated, which means that they're not going to reproduce as easily. If there's less plants, then the ecosystem can support less animals, which means there's less biodiversity and less ecosystem services.

> **Participant**: The whole point, I guess, of this course is to be able to support more food for the increasing human population and if we can't produce more food, then we can't support the human population. There are certain insects that will pollinate plants so they have to be pollinated otherwise, they will die.
> **Interviewer**: You see this as threatening future food production?
> **Participant**: Yes, and biodiversity and--
> **Participant**: Ecosystem services and then sustainability.

In response to how human activity might affect these rates of extinction, Group B identified climate change from carbon emissions, habitat loss, and insecticides as potential causes. They were adamant that human activity is the primary cause of these extinctions: “We're causing the problem and we're causing these species to go extinct.”

When asked to critique hypothetical statements about food production, Group B’s responses centered around the importance of maintaining biodiversity and ecosystem function in habitats adjacent to cropland. They argued that “we do need to increase food production but I don't think the way of doing it is necessarily expanding the fields. Expanding the fields means you're destroying more habitat.” They felt this was problematic because “there are still ecosystems in there and they're still providing ecosystem services” like pollination and beneficial predation of pests.

For the final set of questions, Group B readily provided suggestions for practices that would balance tradeoffs between production and ecological sustainability. In rapid succession, they suggested crop rotation, reduced tillage, minimal application of insecticides, use of cover crops, implementation of habitat corridors, and planting trees along fencerows as windbreaks and riparian buffers. They advocated for land management options that would support “functioning ecosystems” with minimal disturbances. Notably, their suggestions in this case and at other points in the interview seem to correspond to their classroom experiences in which they considered practices on local farms and their ramifications on biodiversity and ecosystem function.

Analysis comments. While Group B framed some of their responses in terms of consumption, they again primarily responded to these questions from a production and stewardship perspective. For example, while they identified climate change from carbon emissions (a) as a potential cause of insect extinctions, they also identified production considerations such as habitat conversion and insecticide use (b3). The extent to which they perceived these questions from potential roles as producers and ecological stewards is particularly evident in their proposed solutions, all of which entailed crop and habitat management considerations (b1, b2).

As such, Group B interpreted these questions in a manner that provided abundant opportunities for them to transfer ideas and practices from the course in their responses. Their advocacy for options such as reduced tillage and insecticide use (b1) as well as adding corridors and riparian buffers (b2) alluded to the need for ecologically sustainable interactions between cultivated fields and less-managed habitats (b3). They also described specific causal mechanisms not only for how agriculture can create habitat disturbances, but also for how biodiversity and ecosystem services like pollination are needed to sustain food production (c).

Group B's discourse patterns also reflected continued engagement and interaction that results from listening and responding. Through these collaborations, their responses addressed the questions more thoroughly and accurately, providing greater utilization of disciplinary language and system models.

Comparison to Initial Interview Performance. Among the three focus groups, Group B demonstrated the greatest improvement from their initial interview performances in regard to framing and transfer. In their initial interview, Group B focused much of their discussions on decisions made by consumers despite their stronger personal connections to production agriculture. However, in their final interview, Group B predominantly framed their responses in terms of production and ecological stewardship roles. They responded in a manner that framed these considerations as pertinent to decisions that people like themselves would make.

Furthermore, Group B demonstrated a greater capacity for transferring ideas and practices from the course to real-world systems compared to their initial interview. At that point, these students struggled to address relationships between agricultural production and ecological function and relied primarily on good/bad heuristics to respond to interview questions. In their final interview, they effectively described how different agriculture production options (b1) could result in different levels of disturbances for habitats in rural agricultural landscapes (b3). For example, while they identified habitat conversion and insecticide use as potential causes of declines in biodiversity, they also advocated for implementing options such as corridors and riparian buffers to improve biodiversity (b2). Similarly, they were able to identify the importance of less-managed lands in rural landscapes in terms of ecosystem services and the benefits these provide for production agriculture (b3, c).

Finally, Group B's capacity for group discourse improved by the final interview. Initially, students did listen and respond to each other's ideas to a limited extent. However, Group B's improved capacity for collaboration was reflected in the greater frequency in which they added on to each other's responses and regularly identified opportunities to reinforce or challenge their claims. As a result, they demonstrated a greater capacity to develop more sophisticated responses through their interactions, particularly by identifying system models, evidence, or anecdotes to reinforce their claims. Finally, their capacity to use disciplinary language to align their responses with ecological norms improved noticeably in comparison to their initial interview. These students used terms and system models with fluency and ease in a manner that enabled them to communicate complex interdependent ideas in a concise and accurate manner.

Relevance to Classroom Implementation. In their final interview, Group B demonstrated the greatest capacity to frame management of rural landscapes and food production through decisions made by both producers and consumers. This undoubtedly was influenced to some extent by their more extensive personal connections to production agriculture. However, Group B also regularly gained opportunities in the classroom to analyze real-world decisions made by local farmers (including their instructor). Given the focus of their ideas and suggestions in the later interviews, and the correlation these have with their instructor's descriptions of her implementation, these classroom opportunities likely played a significant role in improving Group B's capacity for multi-perspective framing on these issues.

Similarly, Group B's opportunities for outdoor investigations likely supported their improved capacities for transfer. Unlike Group A, students in Group B demonstrated a capacity to transfer ideas from the course to the management of both cropland and adjacent habitats in addition to consumption considerations. While Group B had more limited access to authentic production contexts through the course, the way their instructor emphasized overlap between ecological and agricultural decisions likely supported this outcome.

Finally, Group B's performance regarding group discourse reflects their opportunities in class. Their instructor noted the perceived value that their group quizzes had regarding these kinds of performances. Group B's responses during their final interview reflect their regular opportunities to collaboratively develop more sophisticated responses that effectively integrate disciplinary language and system models.

Group C – Absence of Group Discourse & Personal Engagement

Group C completed their final interview shortly before their final exam. In response to the question about the greatest threats to future food production, they argued that the "decrease in the amount of farms" was their top concern because without a sufficient number of farms, "we're not going to be able to provide for our growing population."

Role of biodiversity and ecosystem services. Students in Group C also expressed concerns that invasive species will displace crops and livestock: "Because new species come into the environment and then they have to find something to feed off of and then they might feed off the other species that were already there to begin with." They clarified that they were specifically concerned that invasive species would displace crops and livestock but acknowledged they were unable to explain this in more detail. I then asked if they had concerns that invasive species would "displace something other than crops and livestock and that might have an impact on food production." One student responded, "They can start displacing the pollinators and that would be bad for the food production. … Without pollinators, then you won't have anybody to pollinate the flowers and make them grow into your food production."

I then asked if they had any other concerns about how changes to biodiversity and ecosystem function might pertain to threats to food production. One student responded:

> **Student 2**: Yes, the decrease in biodiversity is also a concern with food production because the less variation … [background conversation] … A decrease in biodiversity, if there's less organisms and animals that humans all may rely on or species that those animals rely on or plants that are frequently eaten just for, not just humans, but other organisms as a whole, [that] is also is a big concern when it comes to food production and biodiversity.

When I asked if they could elaborate on this, the student responded, "Not really, like it's in my head by just can't really piece it together." When asked, Group C could not identify any other threats.

When I asked what solutions Group C recommended to address these threats, their only suggestion was to get more people interested in agriculture: “It would help to show people what’s actually going on and maybe they’ll start getting interested in farming so that the farms and the population would increase.” Another student added, “The more people that are interested in farming, then the more they would want to help.” When asked, Group C was not able to propose any other potential solutions.

Analysis comments. Group C’s responses addressed the threats to food production from a mixture of perspectives. Their identification of decreasing numbers of farms as a key threat in some ways reflected a production perspective, especially the phrase, “we're not going to be able to provide for our growing population.” However, their discussion more emphasized threats imposed on farmers by consumers (a) while largely disregarding the impacts of decisions made by farmers themselves. Similarly, they did not suggest any solutions that pertain to decisions related to production and ecological stewardship (b,c).

As a result, they demonstrated a very limited capacity for transfer at the start of their interview. They addressed topics pertaining to habitat management (b2) in a manner that does not align with the curriculum; for example, the curriculum addresses the harm caused to ecosystem function by invasive species but does not state that species like corn or cattle will be significantly displaced. Similarly, Group C struggled to articulate how changes to biodiversity and ecosystem function might pertain to threats to food production and were unable to provide any solutions that they would have addressed in class during the interview.

At the start of the interview, it was already evident that Group C’s discourse patterns were very different from Groups A and B. Their responses were almost entirely individualized, and they rarely collaborated to build off each other’s ideas. Their responses rarely grew in sophistication as a result and their use of disciplinary language and system models was much more limited. Even in their final interview, their descriptions were primarily comprised of informal language.

Applications of course ideas and practices. Unlike Groups A and B, Group C had encountered the additional questions that I had added to the interview protocol (changes to global biodiversity, assessing claims about marginal land, and designing options to balance tradeoffs) in each of their interviews. Thus, this was their third opportunity to respond to these questions.

In response to the data on insect and vertebrate extinction rates, I asked Group C how these trends might affect ecosystem services and ecosystem function. One student responded:

> With the insects, they're very small, like when you look at them, usually, some of them are bigger, but not really around here. They're more important. Like this extinction is more important than you might think because these vertebrates, a lot of these that we rely on or other species that are important to us rely on are dying out and not just related to food, but also related to food.

When I asked how human activity might be responsible for these extinction rates, one suggested that humans “might try to kill the bees off when they get too close by swatting at them.” Another suggested, “air and water pollution for the vertebrates” as a potential cause. They were unable to elaborate or provide further suggestions, but one student acknowledged that these losses to biodiversity could be problematic: “Some of the insects that have a higher rate of extinction could be pollinators that would affect the crops.”

When asked to critique hypothetical statements about food production, one student expressed concern about a proposal in one of the statements to remove fencerows to expand the fields for larger equipment, as this could reduce biodiversity in that area. Their explanation generally contradicted the course content: “It wouldn't reduce biodiversity by a large amount, but it would take away that small sliver of land between the two..”

In the final block of questions, Group C struggled to provide suggestions for practices that would balance tradeoffs between production and ecological sustainability. One student expressed concern about rodents. Another was interested in whether “there's any forests around and how thick they are to get a good idea for the biodiversity.” When I asked him to elaborate, he explained he was referring to “how big the forest is, how much space they take up,” which he later confirmed was a reference to habitat fragmentation.

Another student suggested it was important to investigate the “soil to see if the specific nutrients that they need to grow that set of crops is in there and how weak or how strong it is.” When I asked Group C to provide recommendations to balance tradeoffs between production and ecological sustainability, they responded, “I don't really know,” and “I've got nothing.”

Analysis comments. Again, the way Group C addressed these questions reflected a mixture of perspectives. In this case, Group C did provide some suggestions that reflected production and stewardship decisions, such as maintaining fencerows as habitat corridors. However, they only provided a limited amount of discussion about decisions that farmers could make to support crop productivity and/or system sustainability.

In response to these questions, Group C did show some improvement in terms of transfer. They were able address habitat management decisions (b2), such as when they identified fencerows as potential habitat corridors with implications for biodiversity, or when they vaguely alluded to habitat fragmentation. They also briefly discussed crop management considerations (b1) when discussing the impact of weeds and pests on crop production. However, these references were generally vague and imprecise, and reflected a limited capacity for these students to apply course ideas and practices in their interview performances.

Finally, in terms of discourse Group C continued to engage individually with very little collaboration. They use comparatively little disciplinary language and struggled to describe phenomena and system models with precision and sophistication.

Comparison to Initial Interview Performance. Group C's responses reflected some progress from their initial interview in terms of framing their responses to include more emphasis on production and ecological stewardship. However, they continued to argue the primary threat was a growing population's consumption paired with limited production from a dwindling number of farms and/or farmers. While they recognized that interactions between cropland and adjacent habitat had implications for food production, they continued have a limited ability to critique decisions made by producers as they pertain to productivity and system sustainability.

Group C also continued to demonstrate a limited capacity to transfer ideas and practices from the course to real-world systems. Despite covering more content than Group B, they demonstrated comparatively limited improvement in using disciplinary language and system models from the course to explain supply-side factors that affect crop productivity and system sustainability. With a few exceptions, they were generally unable to recognize habitat management (b2, b3) concepts (such as fragmentation, ecosystem services, and resilience) or crop production strategies (b1) from the curriculum that were inherent in the contexts of the interview questions. Despite encountering questions about authentic considerations in rural landscapes on multiple occasions, they continued to struggle to effectively identify how these questions pertained to the ideas and practices from the course up to their final interview.

Finally, Group C's discourse patterns during the interviews were distinctly different than either Groups A or B and reflect very little change from their initial interview. Students in Group C rarely collaborated or expanded on each other's ideas. They responded to each question primarily individually, and almost never finished each other's ideas or interrupted to contribute their ideas. Their interviews frequently consisted of long pauses as well as "I don't know" types of responses. While Groups A and B increasingly incorporated experiences from the class and their personal lives to add context and nuance to their responses, Group C almost never provided a similar performance unless explicitly prompted to do so. Finally, Group C demonstrated very little fluency in the disciplinary language of the course and relied almost entirely on informal language throughout the semester.

Relevance to Classroom Implementation. Group C demonstrated the least amount of improvement between their initial and final interviews in terms of framing, transfer, and group discourse. Their limited improvement is very likely an outcome of changes to their opportunities to learn because of COVID-19.

Regarding framing, Group C was similar to Group B in that they also had access to an instructor with direct personal experience in production agriculture who regularly emphasized production contexts. However, Group C lacked the more extensive personal connections to production agriculture that Group B had. Additionally, their opportunities for engagement through discourse were distinctly different because of a mixture of in-person and remote learning students. As such, students from more of a consumer-based background likely had less opportunities to a) personally connect with these perspectives and b) less meaningful engagement when they occurred. As such, it is perhaps unsurprising that Group C's framing changed very little between their initial and final interviews.

These circumstances also had consequences for Group C's capacity for transfer. Group C had no opportunities for engagement in authentic contexts such as local habitats during their instruction. They also were unable to partake in community-based opportunities such as SAEs and field trips. In short, Group C had no access to the aspects of instruction that most affected transfer for Groups A and B. Thus, these students lacked the same level of preparation to identify how the interview questions pertained to the ideas and practices from the course.

Finally, Group C had essentially no access to group discourse through their classroom learning opportunities. While their instructor acknowledged that Group C was “less bubbly” than the previous year’s focus students, Group C lacked the opportunities that Groups A and B had to improve in their capacity to collaborate to improve their responses. Thus, it is unsurprising that Group C demonstrated very little change between their initial and final interviews in this regard.

Comparisons Across the Focus Groups

There were clear differences between the interview performances of each of the three focus groups as well as their classroom experiences. Students in each focus group had differing opportunities to develop their capacities for framing, transfer, and discourse. In addition to their prior knowledge and personal experiences, these opportunities shaped their performances and affected their improvements between the initial and final interviews (summarized in the table below).

Group A. Group A had extensive classroom opportunities for transfer and discourse. They had repeated opportunities to investigate phenomena in authentic contexts (such as local habitats) and regularly engaged in group discourse opportunities. Furthermore, their instructor modeled performances that supported effective reasoning and sensemaking as well as framing their ideas using disciplinary language and system models. However, Group A had comparatively fewer opportunities to frame ideas from the course from multiple perspectives. In particular, students in Group A’s class primarily addressed the course content from the perspectives of consumers and ecological stewardship. This was due both to a limited emphasis on production in the curriculum as well as decisions by the instructor (such as her focus on career preparation and management of recycling in lieu of contextualized discourse during the Day 5 activities). Even though Group A had opportunities for direct engagement with agricultural phenomena (particularly through their field trip), they perceived these opportunities largely from the perspectives of consumers.

As a result, Group A demonstrated improvements between the initial and final exam in regard to their abilities to transfer ideas and practices from the course to authentic contexts (particularly when they pertained to consumption and habitat management). They also improved in their capacity to engage in collaborative discourse to enable more sophisticated responses. However, Group A faced obstacles in achieving the target interview performance because they had a limited capacity to perceive questions about food productivity and sustainability from a production perspective.

Group B. Group B encountered a different classroom environment in which classroom discourse was more scaffolded and opportunities for personal engagement with phenomena were slightly less frequent. Furthermore, Group B did not have a SAE requirement like that of Group A (although many students had similar community-based experiences already). However, Group B also had affordances that Group A did not. Group B's instructor farmed and more frequently contextualized the course content from the perspectives of decisions made by farmers and land managers. In doing so, she referenced familiar examples that were generally accessible to students (such as fields they would pass on their way to school). In addition, Group B had greater funds of knowledge and more personal experience regarding production agriculture. Group B also regularly took part in unit discourse opportunities to connect the course content to different contexts based on students' backgrounds and career goals. Finally, Group B's opportunities to complete weekly assessment questions in consistent groups reflected the kinds of performances they would need to provide during their focus group interviews.

As a result, Group B demonstrated the greatest capacity to frame questions about sustainable food production from a variety of perspectives. This in addition to their opportunities for personal engagement with phenomena supported their capacity to transfer ideas and practices from the course to authentic contexts, especially regarding production and land management decisions. Finally, Group B's opportunities for group discourse provided them with opportunities to improve in their capacity to collaborate to develop sophisticated responses that effectively incorporated disciplinary language and system models.

Group C. While Group C had the same instructor as Group B and learned from the same curriculum as all the focus students, their preparation resulted in very different interview performances. Group C had very little opportunity to frame course content from production perspectives. Furthermore, they had essentially no opportunities to engage with ideas and practices from the course in authentic environments through outdoor investigations, SAEs, or similar opportunities. Finally, students in Group C's class were unable to engage in group discourse and primarily experienced the course through individual writing and whole-class discussion. As such, they had far less opportunity to meaningfully contribute their ideas, listen to their group members, and reinforce or challenge these ideas to develop more sophisticated responses.

The effects of these experiences on their interview performances are quite evident. Group C continued to perceive the interview questions from the perspectives of consumers, with only mild improvement in terms of their capacity to respond from an ecological stewardship perspective. They demonstrated almost no capacity to address the interview questions from the perspectives of producers. In addition, Group C demonstrated a very limited capacity for transfer of course ideas and practices to the contexts inherent in the interview questions. Even in cases where the opportunity to include course content was made explicit by the interviewer, Group C struggled to incorporate disciplinary language and system models from the course. Finally, Group C's interview performances were almost entirely individualized in nature. Students rarely responded to each other's ideas, limiting their capacity to achieve more sophisticated responses through collaboration. This is in stark contrast to Groups A and B, who regularly and consistently used collaboration to respond to ideas, challenge or reinforce them, and apply disciplinary language and system models to achieve greater sophistication and accuracy.

Table 17 – Comparisons Across Focus Group Performances

Group	Framing	Transfer - Demand and Consumption (a)	Transfer - Mgmt of cropland, habitats, and interactions (b)	Transfer - Crop productivity & system sustainability (c)	Discourse
Group A	Emphasis on relationship between technology & consumption	Used classroom ideas & practices to elaborate on how consumption affects natural ecosystems	Used classroom ideas & practices to address habitat mgmt practices (e.g., corridors).	Used classroom ideas & practices to address effects of technological systems on production and consumption.	Demonstrated capacity to listen and collaborate to develop more sophisticated responses
Group B	Primarily focused on production & stewardship	Used classroom ideas & practices to elaborate on how consumption affects natural ecosystems	Used classroom ideas & practices to address mgmt of fields, habitats, and interactions.	Use causal mechanisms from class to explain system sustainability and productivity	Demonstrated capacity to listen and collaborate to develop more sophisticated responses
Group C	Primarily focused on consumer demand	Minimal capacity to use practices to elaborate on how consumption affect natural ecosystems	Minimal capacity to apply classroom ideas & practices to production and habitat mgmt.	Minimal capacity to use causal mechanisms from class to explain system sustainability and productivity	Responses were mostly individualized; minimal collaboration to increase sophistication.

DISCUSSION

In this study, I investigated how students in three focus groups reasoned about land use in rural agricultural areas as a result of three-dimensional ecological learning opportunities in a NGSS-aligned agriscience course. The intent was to determine students' capacities to define problems that can affect agriculture due to reductions to biodiversity, ecosystem services, carrying capacity, and resilience. I assessed changes to students' capacities to address this target performance through multiple focus group interviews. Through these interviews, students were prompted to provide three-dimensional performances to demonstrate their capacities for reasoning and decision-making about agro-ecological phenomena.

Summary of Claims

Successful achievement of the key target performance depended on students' abilities to 1) identify patterns between biodiversity, ecosystem services, carrying capacity, resilience, and human activity; 2) use evidence from examples to support their arguments; and 3) define the problems and solutions using causal mechanisms and system models. To bridge the interview questions and these performances, students needed to be able to:

a. Consider factors that emphasize demand (e.g., population growth and its impact on consumption, associated technologies, and their impact on local and global ecosystems).
b. Address supply side factors associated with patterns of land use in rural landscapes (e.g., managed cropland vs. adjacent habitats) including:
    1. Strategies for managing crop production;
    2. Characteristics of less managed lands (e.g., ecosystem services provided by sufficient levels of biodiversity); and
    3. Interactions between cropland and less managed lands; and…

c. Explain the mechanisms through which these factors affected crop productivity and/or system sustainability.

While students in all three focus groups learned through the same curriculum, differences in students' backgrounds and teacher implementation resulted in different outcomes between the initial and final focus group interviews. In my Results section, I described my findings chronologically on a group-by-group basis. Before describing the implications of my findings, I will summarize differences across all student interview performances through the lenses of framing, transfer, and discourse.

Framing

Throughout this paper, I have defined *framing* as the perspectives from which students perceive and interpret tasks such as interview questions or their classroom performances. To effectively achieve the target interview performances, students needed to simultaneously assume identities as consumers, as production agriculturalists, and as ecological stewards. They needed to identify decisions that pertain to sustainable and sufficient food production from each of these three perspectives and perceive the value in doing so.

Group A students all came from suburban families that were not directly engaged in production agriculture. They had regular opportunities to engage with production perspectives (e.g., managing their recycling program) and habitat management (e.g., outdoor investigations), but they had more limited opportunities to gain experience with production perspectives, limiting their capacity to frame their responses beyond the perspectives of consumers. This meant that they focused more on stewardship than on agricultural production in their perspectives on rural landscapes, limiting their capacity to achieve the key target performance because they often disregarded or minimally considered the implications of production considerations.

In contrast, Group B students had more personal backgrounds in agriculture, and their instructor used her own experiences in production agriculture as well as local relevant examples to contextualize course concepts from each of these perspectives. In addition to outdoor investigations, these opportunities provided valuable preparation for Group B students to frame their interview responses from multiple perspectives in these systems.

Finally, Group C students not only lacked personal backgrounds in agriculture, but they also lacked opportunities to personally engage with agriculture phenomena during their course experiences as a result of COVID-19. As such, they continued to perceive questions about food production and ecological systems predominantly from the perspectives of consumers. They struggled to identify explicit connections between food production and ecological factors such as biodiversity, ecosystem services, resilience, and carrying capacity in part because of their limited perspectives within food production systems.

Transfer

I used the term *transfer* as way to describe students' capacities to connect ideas and practices from one context to another as a means to develop novel explanations and/or solutions for real-world considerations. For students to meaningfully comprehend a phenomenon, it is not enough for them to gain indirect experience through verbal meanings. As Gee (2005, p. 23) argues, individuals are unable to identify connections between course content and authentic contexts unless they have had "embodied experiences" with contextualized phenomena.

Students in Groups A and B had opportunities through their classroom experiences to personally experience phenomena relevant to the course. In addition to investigations situated in their local habitats, students also had opportunities through SAEs (or SAE-like activities), field trips, and managing the school's recycling program. Students in both focus groups as well as their instructors explicitly acknowledged the value of these experiences for bridging classroom concepts with real-world systems.

In contrast, Group C had almost no opportunities for personal engagement with the phenomena they were studying. Due to COVID-19, they had essentially no opportunities for personal engagement with phenomena to contextualize the course content. Despite having successful performances in class, students in Group C were far more limited in their capacity to see how the interview questions pertained to their classroom instruction and struggled to apply ideas and practices from the course in their responses.

As a result of these disparate experiences, there were distinct differences in interview performances. Students in Groups A and B demonstrated significant improvement in their capacity to recognize overlap between interview questions about food production and the ecological ideas and practices from the course. Across subsequent interviews, they continuously incorporated more course content into their interview responses and increasingly recognized subtle connections between the questions and content. In contrast, Group C's responses changed very little across their subsequent interviews. Even in cases where they recognized potential overlap between course content and the interview questions, they were generally unable to transfer ideas and practices from the course to their interview responses in a coherent fashion. This is despite the fact that they demonstrated a proficient capacity to explain ecological phenomena during classroom instruction.

Discourse

Throughout this paper, I have referred to *discourse* as how students engaged in opportunities to express their ideas and build on one another's responses. Successful outcomes in science classrooms depend on ongoing opportunities for scaffolded interpersonal dialogue. As

Gee (2005, p. 28) argues, “social interaction and dialogue … are also crucial” for science learning that is useful for action.

The differences in interview performances among the focus groups alludes to these claims. Groups A and B had regular opportunities to work in small groups to express their ideas and engage in evidence-based argumentation. During their interviews, students in Groups A and B regularly collaborated to reinforce or push back on their peer’s ideas and identify opportunities to improve the sophistication of their responses through the inclusion of disciplinary language and system models.

Additionally, Group B had regular opportunities to engage in group discourse that explicitly supported framing and transfer, particularly on the final day of each unit. As such, these students demonstrated the strongest capacity to achieve the interview target performances. By their final interview, they could use disciplinary language and system models to describe patterns between human activity and ecological function in authentic contexts. They could develop evidence-based arguments about the ramifications of different kinds of human activity pertaining to both production and consumption, and they could define problems and recommend multiple solutions for their surrounding landscapes using causal mechanisms.

In contrast, Group C had almost no opportunities for scaffolded interpersonal dialogue during classroom instruction. Subsequently, Group C’s interview responses were almost entirely individualized. Not only did this affect their capacity to improve the sophistication of their responses during the interview, this also likely affected their preparation prior to the interviews. Without opportunities for dialogue and interaction during the class, students in Group C lacked a crucial opportunity to further develop their capacities for framing and transfer. They demonstrated a very limited their capacity to reason about food production from perspectives other than that of consumers and were generally incapable of recognizing how ideas and practices from the course pertained to the interview questions.

Contributions and Implications

My findings allude to the challenges inherent in enabling more informed decision-making through three-dimensional science learning. In this study, all students gained repeated opportunities for three-dimensional engagement scaffolded by skilled educators with strong scientific backgrounds. However, even with a common NGSS-aligned curriculum, students had widely varying improvements in their capacities to reason about how changes to ecological systems can affect and be affected by human activity like agriculture. This suggests that enabling more informed decision-making through three-dimensional engagement with phenomena may necessitate considerations beyond the classroom itself. In particular, student performances appear to be at least partly determined by their opportunities to reason about problems from multiple perspectives, to gain experience in applying classroom knowledge and practice to authentic contexts, and to collaboratively engage in discourse to deepen their comprehension and develop more sophisticated responses.

Implications and Future Work

The reforms inherent in the *Framework* (NRC, 2012) and NGSS (NGSS Lead States, 2013) are meant to improve individual engagement on scientific issues that arise in personal and professional settings, especially for decisions that will affect the public interest (Rudolph & Horibe, 2016). While these documents pertain to instruction that primarily occurs within classrooms, the findings from this work suggest that the goal of more informed decision-making is also determined in part by students' experiences outside of the classroom. This alludes to the importance of attending to the needs of instructors for addressing aspects such as identity, experience, and discourse in their instruction.

The results of this study address potential opportunities to support teachers in implementing three-dimensional learning and NGSS-aligned curriculum to enable more informed decision-making in authentic contexts. For instance, the difference in focus group outcomes alludes to the importance of framing issues from the perspectives of multiple stakeholders. For decisions about food production, it is not enough for students to understand the issue solely from the lens of consumers. To make fully informed decisions about food production, consumers need to have some understanding of the decisions that agriculturalists and ecologists encounter regarding food production, and how these relate to ecological, economic, and social sustainability.

For students to be able to apply these perspectives to their own decisions, they need "embodied experiences" in authentic relevant settings to contextualize the content in addition to instruction within the classroom. Additionally, students need opportunities to engage in dialogue about these experiences and phenomena as means to deepen their comprehension, situate within multiple contexts, and interact with others to iteratively refine and revise their explanations and solutions.

These conditions likely apply to other key socioscientific topics such as climate change, renewable energy, and others. However, the compounding the complexity of science instruction would complicate the already-difficult task of transitioning teachers away from more traditional approaches to science instruction. Additional studies would be helpful to address the extent to which framing, transfer, and discourse can support more informed decision-making, particularly for topics besides food production. Further research is also needed to determine how to best prepare teachers to implement these strategies, and how to develop curriculum that explicitly incorporates these elements into its design.

Personal and Professional Implications. These findings provide further refinement to my ideas about effective science learning that will be particularly valuable as I return to a high school science teaching position. As a result of my dissertation work and doctoral training, I now have a more precise understanding of how to enact three-dimensional science learning to enable more informed engagement. Furthermore, I more fully appreciate the challenges inherent in developing and supporting these approaches within the constraints and limitations of actual classrooms.

However, I also increasingly recognize the limitations inherent in both the Framework and NGSS and I hope to use my own classroom teaching and research to illuminate potential pathways for improvement. Some of these considerations include a) enabling more productive classroom discourse; b) designing more effective options for student engagement with phenomena; and c) addressing the role of identity and experience through opportunities for framing and transfer.

Productive Classroom Discourse. Numerous scholars have written extensively about the importance of student discourse, resulting in valuable teacher-facing publications such as the *Talk Science Primer* (Michaels & O'Connor, 2012). While these resources provide generalized guidance, my dissertation work has deepened my understanding of how to design specific curricular scaffolds to more effectively and consistently support productive classroom discourse.

For example, each of my FACTS weekly units began with a data dive activity. I had initially incorporated this component primarily to improve students' data literacy. However, the discussions that these activities generated around anchoring phenomena proved to be unexpectedly valuable. Furthermore, my case study teachers enacted modifications that further enhanced the value of these activities. Mrs. E encouraged students to explicitly recognize divergence in their ideas and identify commonality based on evidence as a means to eventually reach consensus. Mrs. B used the data dives to enable students to identify commonalities among their ideas and to reason about how phenomena manifested itself in students' day-to-day experiences in their local community. As I develop curriculum and instruction for my own classroom, I intend to explicitly scaffold these aspects into the data dives as a means to enable more productive classroom discourse.

Similarly, both of my case study teachers modified the weekly review and assessment activities to incorporate more productive classroom discourse. Mrs. E used the review sessions as opportunities for students to demonstrate their capacities to make claims about phenomena as well as critique and evaluate the validity of the claims of their peers. Mrs. B used the assessments themselves as opportunities for students to collaborate to develop three-dimensional responses through verbal discourse. Both of these approaches provided valuable opportunities for students to voice their ideas, deepen their understanding of the course content, and respond to the ideas of their peers in order to develop more sophisticated responses. Both of these approaches also broadened the purpose of the weekly assessments to provide enhanced opportunities for deeper reasoning and sensemaking among students, particularly in novel contexts and circumstances more similar to what they might encounter in real-world settings. I intend to design assessments for use in my own classroom that take advantage of these sensemaking opportunities that are supported by productive discourse.

Transfer: Phenomena in Context. This aspect initially served as the basis of my dissertation and continues to occupy a position of prominence in my work moving forward. As an agriscience instructor, my ideas about situated learning (as embodied in SAEs) evolved significantly over the course of my initial teaching career. Like most agriscience instructors, I initially viewed SAEs as primarily pertaining to career preparation. I initially did not realize the potential value of these opportunities for student reasoning and decision-making.

Through my dissertation work, my ideas about SAEs have continued to expand and evolve. While I still recognize the value of these kinds of opportunities for career preparation, I increasingly recognize their importance for enabling more informed engagement. I now view SAEs as part of a broader category that also includes investigations in authentic settings (like school habitats) as well as well-designed field trips and classroom collaborations with local professionals. I have a broader understanding of the importance of these opportunities for enabling more effective framing and transfer among students in response to course content. I now identify the impact of these opportunities on student reasoning and decision-making as their primary value.

I see this affecting my work as an instructor in multiple ways. First, I better appreciate the limitations of classroom instruction and recognize the need for students to personally engage with phenomena in authentic contexts whenever feasible. I appreciate the tradeoffs inherent in this objective and recognize that reducing some content for richer and more immersive learning opportunities will likely result in more meaningful student outcomes. This increases the impetus for me to seek opportunities for outdoor investigations, direct exposure to local contexts through opportunities like field trips and local collaborations, and for partially structured community-based experiences such as job shadowing.

Finally, I have undergone significant shifts in my views on bridging personal engagement with phenomena and course content through productive classroom discourse. My weekly FACTS units concluded with prompts for discussion to achieve this goal, but I failed to appreciate the value of these discussions for student reasoning and decision-making. Admittedly, these activities were included in part as an option for 'time filler' in the event that teachers completed the units early. While I had hoped that these discussions would occur, I did not consider them to be high priorities. After three years of observing classroom implementation of this curriculum, I have completely shifted my stance on this. I now feel that these discussions play a vital bridge between students' classroom performances and the decisions they will make in authentic contexts outside of school.

Framing: Role of Identity and Experience. One key finding from my work was that students' identities and experiences were an important determinant for whether successful classroom performances translated into successful interview performances. This was particularly evident between Groups A and B. While Group A had demonstrated a capacity to successfully provide three-dimensional performances in authentic contexts, their perceived identities shaped their classroom experiences, which affected their capacities to address production-related components of the interviews. In contrast, Group B's identities and personal experiences enabled them to provide more sophisticated interview responses that addressed problems from multiple relevant perspectives.

This suggests that comprehension of content by itself is not enough to enable more informed decision-making. This outcome also is partly dependent on the capacity for individuals to frame the issue from all relevant perspectives and to recognize where and how ideas and practices from their prior experiences could be relevant for developing explanations and solutions. For classrooms to enable more informed engagement in authentic contexts, it is likely critical that they intentionally address these considerations.

I intend to develop curricular scaffolds that specifically address what funds of knowledge students bring into my classroom and how this shapes their understanding of the phenomena and/or problems that anchor each unit. These prompts could also provide opportunities through classroom discourse for students to share their personal experiences and backgrounds as a means to add depth, nuance, and contextualization to phenomena and/or problems from multiple perspectives. Options like SAEs, field trips, and career shadowing could also provide enhanced opportunities for enhancing and engaging students' funds of knowledge in classroom settings.

Implications for Science Education. These findings could support efforts to design science learning to better prepare students for the roles that scientific knowledge, practice, and discourse will play in their lives. In particular, two outcomes may be particularly valuable for student learning outcomes: 1) designing curricula with transfer in mind, and 2) reimagining the roles served by students' experiences and funds of knowledge.

Transfer through Contextualization of Content. Contextualization of phenomena has a potentially significant impact on students' capacities for informed engagement in authentic contexts outside of schools. Gee (2005) explicitly argues this point when he states that science education is not about "conveying neutral or objective information" but rather "it is about communicating perspectives and experiences and action in the world, often in contrast to alternative and competing perspectives" (p. 28). He goes on to argue that decontextualized content (what he describes using terms such as "verbal language" and "general meanings") is essentially meaningless outside of classrooms. For science learning to be useful for action, students need to develop "situated meanings" (p. 24) for scientific phenomena that contextualizes content in authentic contexts.

This was clearly evident in my findings. While both Groups B and C provided successful classroom performances, they differed significantly in their capacity to recognize and respond to phenomena from the course in non-classroom contexts. Because of appreciable amounts of personal engagement in actual ecosystems and agricultural settings, Group B was far more capable of recognizing phenomena inherent in the interview contexts and responding in a manner informed by ecological knowledge and practice. In contrast, Group C's interview performances changed very little over their subsequent interviews; they generally struggled to transfer the knowledge and practice of the course to settings outside of the course itself. This is despite the fact that they encountered the same curricular content and classroom representations of phenomena as Group B.

This suggests that the notion of transfer entails more than merely using disciplinary core ideas, scientific practices, and crosscutting concepts in different classroom contexts. Rather, to enable students to transfer knowledge and practice from classrooms to authentic considerations, they likely need preparation reflective of conditions that individuals encounter in real-world settings. In addition to more traditional opportunities such as field trips and outdoor investigations, transfer among students could be supported by expanding instruction into community-based settings as well as collaboration with local professionals.

In most classroom-based science learning, however, students currently encounter phenomena through indirect representations. Students' ideas about abstract concepts such as energy, molecular reactions, and ecological interactions are primarily shaped by indirect images, models, or simulations. Even when students are able to physically experience a phenomenon (such as investigations that involve actual organisms or substances), their experiences are comparatively indirect and artificial. For example, students who investigate the growth and function of plants in classroom settings encounter far different conditions than more authentic interactions that are situated in a forest or a field. Admittedly, the constraints and obligations of formal schooling restrict the kinds of options available to teachers and students. However, my work suggests that even within these constraints, there are underutilized opportunities to broaden how students personally encounter phenomena.

Framing Phenomena from Multiple Perspectives. The differences among my focus students' interview performances suggest that their experiences affected their capacity to frame phenomena and problems from multiple perspectives in a system. In particular, Group B's more extensive backgrounds in production agriculture enabled them to better understand, evaluate, and critique food production systems as a whole. More broadly, the funds of knowledge that students bring into the classroom are likely to play an important role for enabling reasoning about phenomena and problems from multiple perspectives in a manner that leads to more informed engagement.

Scaffolded discourse emerged as a key tool for productively leveraging students' funds of knowledge. Through group and whole-class discussion, students identified explicit connections between the course content and their prior experiences. When students shared their experiences and described explicit connections to course content, they provided their peers with additional exposure to phenomena in authentic contexts. Discourse that explicitly addressed how phenomena is embodied in specific contexts better enabled students to "see the meaning" (Gee, 2005, p. 25), resulting in deeper comprehension. By providing planned explicit opportunities for students to identify and share connections between their funds of knowledge and course content, teachers can enable students to shift rote verbal definitions into contextualized comprehension that is useful for action. Gee argues that these discourse opportunities can be enhanced by providing students with longer opportunities to explain their ideas and verbally identify connections to the ideas of other students.

Furthermore, by shadowing local professionals, students could also incorporate the funds of knowledge of the broader community during these discussions. Students with greater exposure to these opportunities generally reasoned about phenomena and problems from a more systemic perspective. This suggests expanding students' funds of knowledge through community interactions can be valuable for enabling more informed engagement with scientific phenomena.

Admittedly, providing students with these kinds of community-based opportunities is likely to be more feasible in an agriscience classroom than a traditional science course. However, science teachers can provide students with curated opportunities to interact with local professionals through more intentional use of guest speakers and field trips. This requires shifting the purpose of these opportunities from being a "hook" or simply a fun and engaging activity to an opportunity for students to engage in meaningful and interactive discourse with local professionals in scientific fields (e.g., medicine or agriculture). In this sense, these opportunities would more resemble scaffolded social science investigations where students collect qualitative data to test their ideas and make predictions about socioscientific phenomena.

It should be noted that the *Framework* and NGSS already address science learning that explicitly incorporates students' backgrounds, lived experiences, and funds of knowledge. However, this is motivated primarily by efforts to improve equity, diversity, and inclusion. For example, the NGSS standards documents (NGSS Lead States, 2013) address students' funds of knowledge in *Appendix D: All Standards, All Studen*ts, arguing that it is vital to "value and respect the experiences that all students bring from their backgrounds" (p. 30). Incorporating students' ideas and experiences is portrayed primarily as a means to enable more effective and equitable learning outcomes, particularly for students from non-dominant groups. While I believe that this should remain a high priority among science educators, my findings suggest that students' funds of knowledge have additional value beyond inclusivity. Incorporating their lived experiences appears to be an important factor for enabling informed engagement outside of classrooms.

Implications for Agricultural Education. These findings also have important implications for agricultural education. The mission statement of school-based agricultural education (SBAE) is to prepare students for "successful careers and a lifetime of informed choices" in agriculture systems (Talbert & Balschweid, 2006, p. 67). Agricultural education exists as a hybrid of science instruction and career and technical education, not only preparing students for agriculture, food, and natural resources (AFNR) careers as they currently exist but also for enacting changes needed to maintain productive and viable AFNR systems. Increasingly, this includes both students who will become agriculturalists as well as those who will be consumers (Talbert & Balschweid, 2006). Preparing students for careers and informed decision-making will almost certainly be complicated by changes and threats posed by climate change, demands from a rising population, and other complex considerations.

My findings suggest that the goal of preparing both future agriculturalists and consumers for informed engagement with agricultural systems is challenging. Additional factors appear to be necessary beyond three-dimensional science learning to enable this outcome. In particular, discourse, transfer, and framing were also critical for enabling informed engagement. These considerations have implications for both traditional classroom-based learning in agriscience, supervised agricultural experiences, and youth organizations.

Implications for Classroom Learning. The opportunities within agricultural education for meaningful contextualization of phenomena emerged as one of the most significant findings from my work. This consideration is already inherent in agriscience courses to some extent due to the nature of content that is centered around real-world considerations. However, my findings suggest that opportunities for students to personally engage with phenomena in authentic meaningful contexts is perhaps as impactful as the content itself. While agricultural education and rural schools in general afford many opportunities for meaningful contextualization of phenomena, these opportunities are generally underutilized.

For example, students who study plant growth and development in horticultural courses not only have deeper contextualization of scientific content, but also tend to have greater opportunities for meaningful engagement through opportunities such as school greenhouses, research plots, and involvement with local professionals. This provides opportunities for students to transfer classroom content to authentic contexts, frame phenomena from multiple systemic perspectives, and engage in discourse to develop situated meaning to support more informed engagement. This is likely to result in more robust learning outcomes in comparison to students whose exposure to plant growth and development is primarily limited to traditional classroom activities. However, most agriscience teachers currently utilize traditional lecture as their primary instructional method (Smith et al., 2015). Students' capacities for framing and transfer could be enhanced by shifting the emphasis of instruction away from teacher-centered approaches towards options that emphasize three-dimensional engagement with phenomena in more authentic settings.

Similarly, rural schools tend to benefit from comparatively stronger relationships with local community members (Knutson & Del Carlo, 2018). Agricultural education can optimize relationships between classrooms and communities through options like supervised agricultural experiences. My findings suggest that interactions with local professionals can be valuable for improving students' capacities to frame phenomena and problems from multiple perspectives as a means to better understand complex systems. Explicit incorporation of community-based interactions into classroom discourse could better support informed engagement after graduation. Intentional inclusion of diverse viewpoints and ideas about agricultural production may also be valuable for shifting student reasoning from good/bad heuristics towards more sophisticated forms of reasoning and decision-making. This would likely require rethinking the role of teachers as primarily a transmitter of rote knowledge to a curator of both local professional expertise as well as scientific research.

Implications for SAEs. Supervised agricultural experiences (SAEs) are currently in the midst of national reform due to declining utilization (Retallick, 2019). As such, conditions are ideal for re-thinking the primary objectives of this instructional opportunity. SAEs are currently framed as a means to enhance specific “industry and career-based competencies” among students (NCAE, 2015, p. 1). However, my findings suggest that SAEs could also support more robust student outcomes beyond rote career skills.

In particular, SAEs could provide valuable opportunities for students to enhance their capacities for informed engagement through an emphasis contextualization of phenomena. This approach could be valuable for improving students’ capacities to transfer knowledge and practice from agricultural courses to authentic contexts in agricultural systems. This could improve student preparation for careers as they exist currently as well as better prepare students to respond to changes that will inevitably emerge within AFNR careers in the coming decades. This is particularly relevant to wicked problems that lack clear answers or solutions but are increasingly prominent in food and natural resources contexts (Murakami et al., 2017).

Prompting students to identify explicit connections between course content and their SAE experiences could also improve their capacities to frame complex questions and problems from a systems-level perspective. Typically, students use SAEs to gain career-based experiences within a particular occupational pathway. However, if SAEs were to be expanded to include multiple stages in the life cycle of a good or service, it would likely expand students' capacities to comprehensively reason about decisions and problems at a systems level.

Implications for the Three Circle Model. Most secondary school-based agricultural education programs in the United States utilize the *Three Circle Model*, which stipulates that agricultural education is comprised of an overlapping blend of classroom instruction, supervised agricultural experiences, and participation in a youth organization (Roberts & Ball, 2009). My findings align well with this model and suggest that instructional approaches in both science and agriculture could inform and enhance the implementation of each subject.

My findings also suggest that the Three Circle Model could potentially be clarified to optimize its impact on student preparation for careers and informed decision-making. In particular, contextualized opportunities inherent in both SAEs as well as participation in the National FFA Organization could be more explicitly incorporated into classroom instruction to enhance opportunities for framing and transfer, particularly during classroom discourse. As mentioned in the previous section, SAEs could also be expanded to more intentionally incorporate diverse viewpoints to expand student reasoning from good/bad heuristics towards more sophisticated forms of sensemaking. This would be particularly valuable for preventing a "backfire effect" in which students question or doubt evidence-based conclusions from their courses due to interactions with an ideologically-motivated community member.

Finally, I opted to minimize my discussion about the impact of involvement in youth organizations like the National FFA as this was not a significant aspect of my data collection. However, involvement in the FFA has immense opportunities for framing, transfer, and discourse as well that are likely underutilized at the moment. For example, FFA members have frequent and repeated opportunities for engagement at local, regional, state, and national events. These include leadership conferences, career development events, and award ceremonies such as state and national conventions. These events often include optional tours of agricultural facilities, interactions with agricultural professionals, and community service and engagement. However, the connections between these opportunities and the mission of more informed decision-making is perhaps not as explicit as it could be. Modifying the implementation of these events to include more opportunities for students to reflect on existing practices and problems in relation to socioscientific phenomena inherent in AFNR systems could optimize student preparation for changing conditions in their future lives and careers.

Limitations

The findings of this paper emerged from three focus groups and two teachers in two schools over a two-year period. Due to interruptions from COVID-19, this study does not resemble the approaches that were originally proposed, nor does it encompass all the forms of data I had intended to collect. In addition, much of the data collection occurred as protocols were still in development. A study with additional forms of data (such as pre/post assessments and additional forms of student work) and a wider range of participants would likely yield more nuanced findings with broader applicability. Furthermore, high school agriscience courses operate in distinctly different ways from their counterparts in science classrooms. As such, the findings here are not meant to represent every high school classroom. However, this paper can provide important contributions for understanding how three-dimensional science learning can be implemented to enable informed decision-making more effectively in authentic contexts.

APPENDICES

APPENDIX A – FACTS Teacher Recruitment Form Questions

1. First and Last Name
2. School District
3. City & State
4. Preferred Email
5. Years of Experience in Teaching (incl. this year).
6. Teaching Certifications (check all that you currently have)
7. Do you currently teach a class that directly pertains to sustainability, or intend to do so in the near future?
8. If you marked "Yes" or "Kind Of" for the question above, have you aligned this course to the 2015 AFNR Standards?
9. Do you currently require students in your courses to have a Supervised Agricultural Experience as a graded component of the course?
10. Would you be interested in testing a pilot curriculum on sustainability in the 2019-20 school year?

APPENDIX B – Focus Group Interview Protocol

Read prior to each interview: *During this interview I will also ask 20 questions about some of your ideas about the things that you have learned since the start of this class. One thing that is important for you to know before we start is that I do not care if your ideas are "right" or "wrong." During the interview I am going to ask you questions like "What do you mean about that?" and "Tell me more about that." I'm not asking these questions because your answers or ideas are wrong. I'm asking those questions because I want to know more about what you think. I won't be giving you a grade for the interview. Your teacher won't know what you say during the interview, and it won't affect your grade in the class. The interview will take about 30-60 minutes and I will use this machine to record what we are saying. Only researchers at Michigan State University will be able to hear the recording, so it will be private. Your teacher, classmates, parents or friends will not hear it. Do you have any questions before we start?*

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By 2050, we will need to produce roughly 70% more food than we are today to accommodate the estimated level of consumption. However, some have suggested that there are reasons to be concerned about sustaining even our current level of food production.

1. In your opinion, what are the greatest threats to future food production?
(if it does not come up, specifically ask students how changes to biodiversity and ecosystem function might affect future food production, if at all).

2. What do you think should be done about these threats to future food production? What solutions do you recommend (if any)?
(if it does not come up, specifically ask students what personal role(s) they might play in regards to these solutions, if any).

3. What, if anything, do you see as your personal role in regards to either causing or solving these threats? Explain your reasoning.

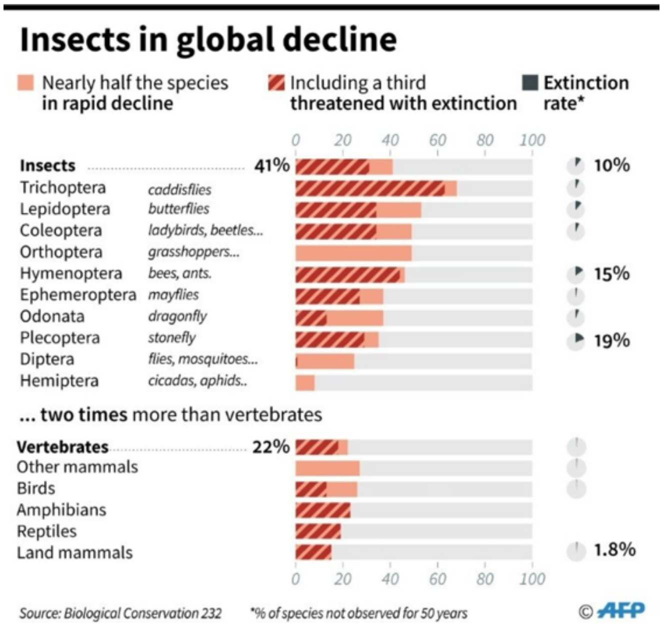

Figure 1 – Losses to Insect Biodiversity

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The figure on the previous page shows the number of species that have already gone extinct. The center shows the number of species that are threatened. The top shows insect data, while the bottom shows vertebrate data.

4. What do you notice about the extinction rates of insects in comparison to vertebrates?
5. How might the rate of extinction of these species affect habitat carrying capacity, ecosystem function, and ecosystem services (if at all)?
6. This data reflects global trends. Do you think that insects are similarly threatened in the area in which you live? Why or why not?
7. What are some important local considerations that might affect the levels of insect biodiversity in the area in which you live? How might they increase or decrease insect biodiversity?

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A journalist is writing an article on agricultural sustainability. The journalist interviews three people and asks them to describe how they think that farmers should manage the portions of their land that are not used for food production. Their responses are included on the following slides.

<u>Dakota</u>: *Food production needs to increase by 25-70% in the next three decades. Fields need to be expanded so that they can grow more food and accommodate the large machinery that is needed to produce this much food. This means eliminating the wasted land between fields, such as fencerows and marginal land, and converting those areas into more useful crop-producing land.*

8. In what ways do you think Dakota's statement is accurate or inaccurate?

<u>Robin</u>: *Modern agriculture is too damaging to the environment. In particular, the use of herbicides and GMOs are detrimental to wildlife habitat and should be banned. Similarly, farmers should be banned from removing weeds and eliminating pests from their fields - we should be maximizing all biodiversity as much as possible in all rural landscapes.*

9. In what ways do you think Robin's statement is accurate or inaccurate?

<u>Finley</u>: *Farmers have to consider both the pressures of growing sufficient amounts of food in a profitable manner as well as the need to manage much of the nation's wildlife habitat. This can be achieved on conventional farms by converting unproductive land into wildlife habitat and connecting habitats with corridors such as fencerows and buffer strips. Land that is productive for food production should not be expanded but should be used as efficiently and sustainably as possible.*

10. In what ways do you think Finley's statement is accurate or inaccurate?

11. Whose statement most aligns with your views on this issue? Why?

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Imagine a scenario in which a farmer-owned food company has hired you as a consultant.

Their marketing research has shown that consumers are increasingly interested in "sustainable food production". You have been asked to tour a local farm and provide a demonstration of how you might improve a farm's practices to make the operation more sustainable.

12. What are some possible questions that you might need to ask a farmer in order to determine which changes would be most useful for improving the sustainability of their operation?

13. What are some feasible recommendations for conventional agricultural operations that would improve their land's biodiversity, ecosystem services, and ecosystem function?

Focus your recommendations on the portions of the farm that are not used for producing crops (areas such as wildlife habitat, fencerows, etc.). Please provide evidence and reasoning that demonstrate how and why these changes could be helpful.

Note that farms usually contain a mixture of both wildlife habitat as well as cropland or pasture. Farms can also contain land between habitat and fields such as fencerows and "buffer strips". Farmers are responsible for making the management decisions for all lands that they own.

==

14. Have your views on any topics related to this course changed since the beginning of the semester and/or since we last spoke?
    A. If so, what aspects of the course most contributed to these changes?
    B. If not, why do you think that is?

15. What aspects of the course (if any) most affected your views on these topics, if any? Why?

16. Briefly describe the community-based experiences you had outside the classroom (field trips, job shadowing, etc.) and how this affected your understanding of the course content.

17. Is there anything that you have started doing differently outside of the classroom as a result of your experiences in this class?

18. Is there anything you intend to do differently as an adult as a result of your experiences in this class?

19. Are there any stances or pieces of information that were presented in this course that you still question or doubt?

20. Is there anything else that you would like to share?

APPENDIX C – Initial Coding Framework for Student Interview Transcripts

Table 18 - Initial Coding Framework for Student Interview Transcripts

Levels	**Summary of Conditions**	*General Example 1*	*General Example 2*
Level 5 - Precise Causal Mechanism w/ Systems Level Analysis	"If X, then Y, because Z" -Precise causal mechanism between 2+ phenomena, AND -Precise use of disc. language w/o assistance, AND -Uses systems-level analysis (describes interactions of multiple components in a system). *(if lacking an aspect = L3)*	*The greater the biodiversity, the greater the ecosystem services because there are more species to fill niches (such as how there are multiple kinds of pollinators in case one goes extinct).*	*The adoption of no-till and cover crops reduces rates of erosion and runoff by providing greater amounts of soil organic matter, which is needed to provide adequate soil structure.*
Level 4 - Complex Systems Correlation	"If X, then Y, and then Z" -Precisely describes correlation between 3+ phenom, AND -Uses precise disc language w/o assistance, AND -Uses systems-level analysis *(if lacking an aspect = L3)*	*If you increase the amount of biomass production, the ecosystem can support larger amounts of biodiversity due to the 10% rule. This results in a more resilient ecosystem that can provide greater levels of ecosystem services.*	*If farmers adopt practices like no-till and cover crops, they will reduce rates of erosion and increase infiltration, which reduces the amount of nutrients entering waterways and reduces the problem of eutrophication.*
Level 3a - Simple Causal Mechanism (w/o errors)	"X is good because…" -Accurately describes an explicit relationship between two phenomena (NOT single actor causation - see 2c). -Uses disc language and systems analysis.	*Biodiversity is important because it increases ecosystem services, like how some insects pollinate crops.* *Plants are key to ecosystems because of the 10% rule.*	*Cover crops are good because they reduce rates of runoff.* *Corridors help because they allow species to move back and forth.*

Table 18 (cont'd)

Level 3b - Simple Correlation Heuristic (w/o errors)	"If X, then Y" -Accurately describes an explicit relationship between two phenomena. -Uses disc language and systems analysis.	*If biodiversity increases, so do ecosystem services.* *The more biomass production, the greater the carrying capacity.*	*The more farmers adopt practices like no-till, the less pollution their farms will create.*
Level 2a - Good/Bad w/ Disc Language	"X is good, Y is bad" -Provides values judgment of whether a condition/outcome is favorable or not w/o justification using minimal disc language and/or ecological models.	*The more biodiversity, the better.*	*Conventional ag is bad for the environment.*
Level 2b - Circle of Life	"Everything is connected and important"	*Everything in an ecosystem matters, like some bugs might help us in ways we don't know.*	*We should preserve habitats because you never know what might be there that could be useful.*
Level 2c - Single Actor Causation w/o Disc Language/Systems	"Bees are pollinators" OR "Plants absorb CO2" A specific species/phenomenon is favorable/harmful based on a specific outcome. Does not use any disciplinary language and/or systems-level analysis	*Pollinators are good because they help crops.* *Plants help by absorbing CO2.*	*Climate change is bad because all those emissions.* *Overusing a field reduces nutrients.*
Level 2d - Inaccurate Grasp of DL, Causal Mech, or Correlation.	"X because {wrong answer}" OR "If X, then Z {not Y}" Inaccurately describes a simple causal mechanism or correlation that otherwise would be Level 3a/b or uses disc language in a way that suggests lack of comprehension.	*if there's greater biodiversity on the farm and if there was like one end that had less biodiversity and another had more*	*Fossil fuels ruin the environment and oxygen. That disrupts photosynthesis, which is important for food production.*

Table 18 (cont'd)

Level 1a - Ag and Ecology are Separate	Suggests that agricultural productivity is disconnected from the ecological factors OR that conv ag doesn't create ecosystem disturbances.	*Farming is really good for the environment and for the human population, even though it's just a lot of work.*	*I think farmers in the US are fine because they're regulated and stuff, but farming practices elsewhere are concerning.*
Level 1b - Don't Know	Explicitly acknowledges they don't know or don't understand.	*I don't know*	*I have no idea.*
Level X - Uncodable	Does not address relationships between agricultural production and ecological function.	*Growing populations will require more food.*	*Consumers are often misinformed.*

APPENDIX D – Teacher Interview Protocol

1. How are things going?

2. What do you like about teaching FACTS? What has been challenging or stressful?

3. Describe how you would cover a typical weekly unit in this course. In particular, describe how you might facilitate and support the following...

   Unit introduction: how do you introduce new content to students? Do you regularly use any strategies that connect the lesson to prior content, make the unit more relevant to student backgrounds/interests, or elicit students' prior knowledge?

   Discussion: how do you support group and/or whole-class discussion that deepens student reasoning & sense-making?

   Group work: what strategies (if any) do you use to maximize student reasoning and thinking in small groups?

   Individual work: what strategies (if any) do you use to maximize student reasoning and thinking on an individualized basis?

   Conclusion: what strategies (if any) do you use to help students to reflect on changes to their initial ideas, recognize relationships across content, and/or connect the content to contexts that are relevant to their lives?

4. The primary goal with this curriculum is to maximize student readiness to make informed decision about rural land management.

   What aspects of your teaching seem most important for achieving this goal? What evidence do you have to support this conclusion?

   What challenges or obstacles have you encountered in trying to create this kind of learning environment?

5. What aspects of the FACTS curriculum have you felt the need to change or modify?

   Why did this seem necessary?

   Do you feel that these change improved student outcomes such as sense-making and reasoning about rural ecological sustainability? If so, describe how.

   Are there other changes that you would like to make or you would recommend that I make?

6. Do you have any evidence or observations that would indicate that students are improving in regards to their capacity to…

   Explain the relationships between levels of biodiversity, carrying capacity, ecosystem services, and the limited capacity for agriculture and other forms of human activity.

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

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

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.

7. Are there any factors outside of your classroom instruction that might have affected the extent to which the objectives in the prior question were met? How was students' learning affected by:

Outdoor labs?

Career shadowing?

Learning from their homes or other community members?

If so, do you have any examples? If not, why do you think that this was the case?

Is there anything else outside of the curriculum that might have affected these student outcomes that should be documented?

8. A key goal of this work is to enable transfer from the classroom to real-world scenarios, particularly among future agriculturalists. Have you observed any evidence that might suggest that student experiences in this course have affected decisions they are making outside of the classroom?

If so, what are some examples that you could share?

If not, what changes or additions do you think would be necessary for this to occur?

9. Do you think that other teachers would be willing to utilize a curriculum such as this in their own classrooms? Or do you think that only a small niche of teachers would be interested in either this kind of content and/or this kind of approach to agriscience instruction?

10. Is there anything else that you'd like to share?

APPENDIX E – FACTS Classroom Discourse Guides

Overview: Data Dives are exercises in which students are presented with data from experiments or scenarios, and are asked to identify trends and develop explanatory models in a process that is very similar to what actual scientists do on a regular basis. This particular Data Dive is more of a Case Study due to the fact that it deals more with an authentic scenario than data from an experiment.

Directions: Students should consider the data or scenario in their assigned groups. They should work with their group members to make sense of the information provided and try to determine the conclusions that can be drawn from it. Students may struggle with this, especially in their first attempts and particularly if your students have limited experience reading graphs and data tables. It may be necessary for you to project the data onto a large screen and guide students by explaining the steps that you would use to make sense of what is being reported. This may be difficult; just like explaining the steps of tying your shoes can be challenging because you rarely have to think about it, it can be exceptionally challenging for someone who is scientifically literate to identify the thought processes that they use to make sense of data. It may be helpful to jot down your ideas in advance and have them ready prior to the start of this class.

Students are likely to struggle to varying extents. That is ok! Be sure to float from group to group to assist. Be sure to remind group members to help each other out. It might ideal to assign groups with a mix of abilities. Encouraging struggling students to work with their better-prepared peers, and conversely, encouraging high performing students to advance their abilities by working with individuals with different skill sets helps to prepare students for the kinds of situations they will encounter in their careers and personal lives.

Plan to allow for about 15-20 minutes to introduce the activity and review how to interpret this information with your students. About a third to half of the class period should be reserved for allowing students to work in their individual groups. The remaining time should be reserved for intergroup or whole-class discussion so that students can engage in scientific debate and argumentation.

It would a good idea to remind students that the term *argumentation* is used differently between scientists and the general public. While argumentation generally has a negative connotation (such as a "heated argument"), argumentation among scientists is generally very good-natured and polite. The goal is not to "win" an argument but rather to expand the understanding of the phenomenon by all involved. Often scientists on opposing sides of an issue will both change their stance as a result of the improved understanding that results from engaging in argumentation. Similarly, students should not be trying to disprove each other or prove that they have the "right" answer. Rather, students should be examining the differences in their conclusions, the manner in which each conclusion was reached, and the similarities and agreements that exist among different conclusions.

Students may reach a conclusion that is not entirely supported by evidence. The temptation may be to point out errors in their reasoning. However, when students are struggling, they are also likely improving their abilities in evidence-based reasoning, which is one of the most important goals of this kind of instruction. Try to resist the urge to correct student errors; rather, try to probe their understanding and challenge them to re-examine the evidence to check the validity of their conclusions and the conclusions of other groups. Consider using the 9 Talk Moves (next page) to support productive classroom dialogue.

Remember – students should re-visit their explanations and models repeatedly over the course the week. If they don't get it right on the first try, they will have more opportunities to do so.

Goals for Productive Discussions and Nine Talk Moves

Goal: Individual students share, expand and clarify their own thinking

1. Time to Think:

Partner Talk
Writing as Think Time Wait Time

2. Say More: "Can you say more about that?" "What do you mean by that?" "Can you give an example?"

3. So, Are You Saying...?:

"So, let me see if I've got what you're saying. Are you saying...?" (always leaving space for the original student to agree or disagree and say more)

Goal: Students listen carefully to one another

4. Who Can Rephrase or Repeat?

"Who can repeat what Javon just said or put it into their own words?" (After a partner talk) "What did your partner say?"

Goal: Students deepen their reasoning

5. Asking for Evidence or Reasoning:

"Why do you think that?" "What's your evidence?" "How did you arrive at that conclusion?" "Is there anything in the text that made you think that?"

6. Challenge or Counterexample:

"Does it always work that way?" "How does that idea square with Sonia's example?" "What if it had been a copper cube instead?"

Goal: Students think with others

7. Agree/Disagree and Why?:

"Do you agree/disagree? (And why?)" "Are you saying the same thing as Jelya or something different, and if it's different, how is it different?" "What do people think about what Vannia said?"
"Does anyone want to respond to that idea?"

8. Add On:

"Who can add onto the idea that Jamal is building?"
"Can anyone take that suggestion and push it a little further?"

9. Explaining What Someone Else Means:

"Who can explain what Aisha means when she says that?" "Who thinks they could explain in their words why Simon came up with that answer?" "Why do you think he said that?"

Source: https://inquiryproject.terc.edu/shared/pd/TalkScience_Primer.pdf

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