

DIVERSE APPROACHES IN AGRICULTURE AND EDUCATION ENHANCE
PROBLEM-SOLVING CAPACITY

by

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of

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in

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DEDICATION

This is dedicated to my wife, Madison. For the many nights I was busy with my work, you kept me fed, supported, and always made me feel loved. I am forever grateful for your loving support.

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ABSTRACT

As humanity faces challenges to feeding itself amidst increasing rates of environmental degradation and disconnection from our food growing ways, we have a responsibility to not only work towards transforming our agricultural systems to be more sustainable, but to prepare the future generation of leaders with the skills, knowledge, and problem-solving approaches that are necessary to handle these challenges. This interdisciplinary dissertation utilizes mixed methods including quantitative and qualitative methodologies to examine problems that range from management of small-scale vegetable systems to pedagogical and systemic approaches in our post-secondary educational systems. An overarching theme emerges that calls on diversifying the way we manage soils and classrooms alike. Chapter One discusses philosophical assumptions and interpretive frameworks that underlie our institutional inquiry apparatus. It also discusses my positionality as a researcher working in this problem space. Chapter Two outlines the foundation of literature that supports the three primary research chapters. Chapter Three reports on research on soil fertility in organic high tunnel vegetable production and concludes that utilizing organic amendments that provide rapid short term Nitrogen release are important to crop yield. Chapter four investigates the effect of an active learning intervention on the capacity for upper-level cropping systems students to quantitatively reason and critically think about complex soil health concepts situated in real-world contexts. The evidence in support of active learning to compliment didactic instruction is clear. Chapter Five explores undergraduate student perceptions of sustainability using a grounded theory study approach. The emergent conceptual model describes one's background knowledge, life and educational experiences, point of view, and existing interest as the primary factors affecting how they evaluate sustainability in any given context. These findings support the use of campus farms for deep learning. Chapter Six includes personal reflection and ties together themes that identify the importance of using diverse approaches in our agricultural management, pedagogical and curricular development, and systemic models of knowledge construction in order to advance society towards a more sustainable future on this planet.

CHAPTER ONE

INTRODUCTION

Scope of Interdisciplinary PhD

As humanity faces challenges to forge a sustainable existence on this planet, the fields of agriculture and education will play key roles in generating solutions. Agricultural science holds potential to provide valuable insight on how food production systems align with ecosystem and climate goals from mechanistic microbiological function to regional systems approaches. The field of education holds insight from disciplinary and philosophical contexts that include psychology, education, sociology, and cognitive science that will be important in aligning social systems and cultural roles with ecological and climate goals. Together, these fields promote a discussion that dynamically integrates technical and mechanistic approaches to understanding the natural world with complementary social-centered and systems-thinking approaches that ensure holistic and appropriate implementation of potential solutions.

This dissertation is the product of an Individual Interdisciplinary PhD program spanning the Plant Sciences and Plant Pathology and Education Departments at Montana State University. It was born from my desire to gain technical knowledge and practical experience growing food as well as to deepen my understanding of the phenomena of teaching and learning, while also gaining experience as a teacher. The field of agriculture encompasses my first academic love found in biology and ecology, and is a uniquely applied field. I've been lucky enough to experience a handful of truly transformative teachers in my life, the most recent of which changed the trajectory of my life by instilling a curiosity of food and opening my eyes to the idea

that our food production systems should be modeled on ecological principles. While I am drawn to the field of psychology and other learning related fields, the true impetus for my pursuit to be an educator comes from a desire to positively influence future students of my own.

Thus, it is a result of my own hard work, and from the support of countless educators who have lifted me up along the way, that I present my dissertation titled, “Diverse active learning experiences integrated with applied research equips students with nuanced understanding of food-system complexity.” This three-article dissertation includes an introduction, a review of literature related to my program of study, three chapters that present my primary research in the fields of agriculture and education, and a concluding chapter aimed to summarize and unify major themes that emerged throughout my academic career at MSU. I conclude my dissertation by elucidating my personal conception of learning. It will become apparent that the intersection of agriculture and education present rich opportunities for learning to occur for students, teachers, and farmers alike. Given the interdisciplinary nature of my program, and the interdisciplinary nature of both agriculture and education, you will find a major emphasis on holistic thinking and the application of active and experiential learning principles to enhance student learning throughout each of my chapters.

While my third chapter presents research conducted with the goal of understanding physical and biological processes related to agricultural production, and it targets a technical journal audience, the research I conducted cannot be separated from the context in which it occurred. In this case, the technical horticulture chapter of my dissertation occurred on a student farm and with assistance from undergraduate students throughout every step of the research process. While the chapter manuscript primarily conveys our scientific understanding of soil

processes, I will include reflections about the significance of this project to undergraduate learning and engagement in my conclusion (chapter 6). It is also worth noting that the research presented in this chapter is specifically aimed to enhance understanding of complex biological processes in a way that can be useful for agricultural practitioners, as the research itself was inspired by real-world challenges identified in farmer surveys. In this way, the educational focus of this chapter may have indirect links to undergraduate learning, but directly contributes to the education of practicing farmers.

Chapter Four is a quantitative research manuscript that builds to the evidence base on the value of utilizing active learning strategies when teaching inherently nuanced and applied concepts. Chapter Five is a qualitative research manuscript that aims to understand how undergraduates grapple with agricultural complexity. The mixed methods approach taken in this interdisciplinary program creates a robust evidence base and context from which I can draw inference. The ways in which each of these research projects relate to overarching dissertation themes will be directly addressed in their respective chapters. In the conclusion chapter, I will reiterate how insights gained from each chapter will contribute to our capacity as a society to generate solutions to the myriad of issues facing our food-system.

Before diving into a review of literature and my primary research, I will discuss how philosophical assumptions, interpretive frameworks, and personal background affect my research process. Including context and personality not only humanizes this work, but since I conducted educational research in a social setting, conveying my positionality as the researcher provides a more holistic and authentic portrayal of my research efforts. My self, which is a culmination of my lived experiences, skills, and knowledge, is an instrument in the research I conducted through

which I co-constructed research findings with my study participants. Because this is one of the defining characteristics of the methods I employed in one of my chapters (five), understanding my positionality will help the reader to make sense of my research findings.

A Note on Philosophical Assumptions and Interpretive Frameworks

The significance of selecting appropriate methods used in scientific inquiry cannot be overstated. Utilization of appropriate assessment and measurement tools have consequences on the validity and implications of your research. While there exists a broad array of tools available to make scientific inference, I will only discuss ones that are relevant to my PhD program. Disciplinary contexts for scientific inquiry influence the specific methods and tools adopted, but there are also general principles that apply across disciplines that can aid in these decisions. Before diving into discussion on the use of specific assessment and measurement tools, I will briefly discuss the philosophical and practical basis of scientific inquiry to provide context from which these methods emerged.

As a Doctor of Philosophy candidate, I find it necessary to elucidate some of the philosophical assumptions and interpretive frameworks that underlie my work. Philosophical assumptions are, “beliefs about ontology (the nature of reality), epistemology (what counts as knowledge and how knowledge claims are justified), axiology (the role of values in research), and methodology (the process of research)” (Creswell & Poth, 2018, p. 19-20). As a researcher considers these philosophical assumptions, they come to embody beliefs or paradigms that they bring into their research process. These beliefs, as well as theories and frameworks that uphold and guide your research process, are referred to as interpretive frameworks (Creswell & Poth, 2018). While it is uncommon to declare these details in quantitative research, the articulation of

these philosophical assumptions and interpretive frameworks are a defining feature of qualitative research. Therefore, as it is imperative to ground my qualitative research in these descriptions, I will also include a description of assumptions and frameworks that guide my quantitative research.

As plant scientists and educators, we are interested in learning about the workings of the natural world and the nature of human learning. The Western scientific method was initially formulated by Francis Bacon as an inductive process of inquiry and truth-seeking in the 17th century (Taper & Lele, 2010). However, modern science now employs both inductive and deductive approaches (Popper, 1959; Hesse, 1974; Taper & Lele, 2010). Both strategies seek to uncover the truth about the natural world through a process of trial and error using observation and experimentation (Salmon, 2017). Inductive approaches are characteristic of new fields that use observations to make generalizations and generate hypotheses. Deductive approaches are characteristic of more mature fields where data is gathered with the intent to falsify or confirm empirically derived hypotheses. Yet, inquiry in most fields utilize both modes of scientific practice.

Science operates under a broad spectrum of philosophies, yet most modern scientists embody the philosophical approach of naturalistic realism (Taper & Lele, 2010). This philosophy welcomes scientific inferences gained from establishing models of reality that are systematically compared to the real world to determine their validity and utility in understanding how the world works (Giere, 1999). This diverges from other prominent philosophies such as logical empiricism and rationalism in that it recognizes: a) that subjectivity and the social construction of reality prohibits our ability to declare immutable laws of nature, although there still exist

intrinsic properties that humans can infer; and b) that truly objective methods to uncover truth do not exist, but scientists have the capacity to approximate nature through construction of approximate theories. Some refutations of this philosophy bolster the role of human reason as an agent to influence our understanding of reality, but know that most modern scientific inquiry operates somewhere on the spectrum between these philosophies: realism, rationalism, and empiricism (Efron and Fisch, 1991).

The cornerstone of science, then, is the notion that these theories, models, or hypotheses of reality need to be testable and evaluated for correctness (Taper & Lele, 2010). It is uncommon practice in science to specify underlying philosophical frameworks. Instead, scientists invoke implicit guidelines that inform the types of questions they can ask and the appropriate data and methods for answering such questions (Taper & Lele, 2010). These implicit characteristics of a given scientific approach are related to disciplinary differences in epistemological approaches which influence the techniques and methods that are appropriate to construct such knowledge. As such, the diversity of approaches and the specialization of tools utilized allow for progressively complex approximations of how the natural world works (Taper & Lele, 2010). Yet, due to this increasing specialization in methodologies and the limited nature of human perspective, no single discipline can explain everything.

Elucidating assumptions embedded in scientific inference will enrich our capacity to ask relevant questions and design research programs that utilize appropriate methods of observation and data collection. Plant sciences and education provide a rich example of how disciplinary contexts can dictate methodological approaches.

Let's begin by examining philosophical beliefs that underlie knowledge inquiry in each discipline. Plant sciences, being considered a natural science, predominantly operates under a framework resembling naturalistic realism (as mentioned above), positioning the scientist with the capacity to describe patterns and represent reality based on physical observation and experimentation. Educational research also utilizes this philosophical framework, where humans serve as a proxy for the natural world and are subject to observation, experimentation, and manipulation. These underlying philosophical beliefs remains relevant to most quantitative research in plants sciences and education. In these contexts, knowledge is inferred through the quantification of elements and their relationships in nature and humans. It is requisite that tools of measurement must be quantifiable. This type of research seeks to minimize and control human interference on the inference process. Quantitative models of reality must account for uncertainty associated with measurement instruments and the inherent variation in natural systems (including humans). Therefore, selection of research designs that reduce bias and deployment of measurement instruments with known precision and accuracy is paramount to drawing inference.

Let us examine an example of how I came to select specific measurement tools for an applied agricultural research project investigating the effect that organic soil amendment composition had on high tunnel vegetable yields (Chapter Three). Through examination of prior literature and a conceptual understanding of factors influencing plant growth and development, we selected organic soil amendments with varying concentrations of N as our treatment factor. Since this research occurred in a biological system, we selected a response factor that was suspected to respond differently to the varying levels of treatment applied. Further, since it was applied research, we also wanted our response variable to be meaningful in the applied setting.

We also tried to minimize the confounding nature of environmental variability and human imposition through use of controls, replication, blocking, and randomization in a balanced research design. Consistency was assured through establishment of detailed protocols and measurement criteria. In this example, measuring yield was both biologically and agriculturally appropriate. These steps are intended to increase our power of inference – to increase the chances that any differences observed are a result of treatment effects and not experimental error.

It is common to have more than one response variable in applied agricultural research. With the hope to increase our capacity to draw inference from the research, we also collected measurements of soil nitrate. This seemed biologically appropriate given the potential relationship between soil amendment composition, nutrient mineralization rates, and plant growth. However, measuring nitrate is not as meaningful in an applied sense because soil nitrate levels are agriculturally and economically less important than yield. Further, due to the poorly understood mechanisms of nitrogen mineralization and nitrogen uptake in plants, the spatial and temporal heterogeneity of soil nitrate, inconsistent and crude sampling techniques, and variability associated with lab testing, measuring soil nitrate turned out to be a poor predictor of yield. In this case, the explanatory power of soil nitrate levels was limited despite our attempts to minimize compounding environmental variability and human interference, the inherent variability of natural systems, and the uncertainty associated with our measurement tool.

Conducting experimental (quantitative by nature) educational research with human subjects requires a similar need to select appropriate experimental design and assessment tools that control for confounding variables. Since treatments are applied to humans and responses measured are artifacts of human cognition, special consideration is needed to account for

uniquely psychological threats to internal and external validity. Internal validity is a requisite for interpretability – without which you cannot have confidence that differences measured were the results of experimental treatments (Campbell & Stanley, 1966). Chapter Four reports on a Solomon four-group classroom experiment designed to examine whether an active learning intervention affects students quantitative reasoning skills. This design was chosen for its capacity to enhance the external validity or generalizability of our findings. Of particular concern is the testing effect that administering a pre-test can have on priming both control and experimental groups (Campbell & Stanley, 1966). In a standard pretest-posttest two group design, both groups receive a pre-test and it eliminates our ability to infer if any differences in groups are attributed to the intervention or the pre-test. The Solomon four-group design is more robust and includes one set of experimental and control groups who receive a pretest and one set of experimental and control groups who do not. In this example, careful selection in the way we structure data collection enhances our power to draw inference from our assessment of student learning.

Quantitative research is not the only way to investigate the world and draw inference, however. Qualitative research utilizes different methodologies and allows for different types of questions to be asked altogether. It is not simply an alternative way to do the same thing [as quantitative research] (Maxwell, 2013). Qualitative approaches to inquiry allow for nuance and multiplicity to emerge from descriptive data. It is a process-oriented approach, meaning it views the world in terms of people, situations, events, and processes, and seeks to make meaning by considering how they influence each other (Maxwell, 2013). Contrast this to the variance-oriented approach of quantitative research that seeks to understand the world in terms of variables and relationships (Maxwell, 2013). Since education is a discipline that encompasses

multiple fields such as, but not limited to, psychology, sociology, philosophy, and cognitive and neuroscience, it draws upon a wider variety of philosophical beliefs that are dependent on the scope of inquiry. Due to the diversity of philosophies underlying education, research approaches require a wider range of methods to gain inference (i.e., quantitative and qualitative methods). Because of the diversity of approaches with different philosophical assumptions, it is common in qualitative research to specify an interpretive framework that positions the work. In quantitative research, we try to minimize the confounding nature of environmental variability and human imposition through use of controls, replication, blocking, and randomization in balanced research design, and we achieve consistency through establishment of detail protocols and measurement criteria. Qualitative researchers elucidate their philosophical assumptions and interpretive frameworks to convey similar ideas of credibility, authenticity, trustworthiness, and transferability. For example, depending on the goal of the researcher and their philosophical beliefs (i.e., ontological, epistemological, axiological, and methodological), qualitative educational research inquiry might utilize several different interpretive frameworks such as postpositivism, social constructivism, pragmatism, etc. (Creswell & Poth, 2018). The philosophical belief, interpretive framework, and specific research approach utilized for qualitative educational research dictates the kind of data collected and strategy used to analyze. In this case, inference is not made through hypothesis testing, but rather through human interpretation using a specific lens. There are inherent limitation to qualitative approaches and times when these methods are appropriate, but it is not meant to replace quantitative approaches.

The research in Chapter Five aims to better understand undergraduate student perceptions of food-system sustainability and how their educational and life experiences inform these

perceptions. Given the complexity of the concept and the social context in which it arises, it investigates the process of how students synthesize their knowledge and experience to evaluate sustainability in real-world contexts. To address this process-oriented question, I chose a grounded theory approach operating under a constructivist paradigm as I am interested in the meaning of sustainability for each participant and what experiences and social contexts have formed these perspectives. The approach serves to yield a model that describes important mental and social processes involved in a students' reckoning of sustainability. Further consideration of my research goals prompt me to use Charmaz's (2014) constructivist approach to grounded theory over Corbin and Strauss's (2015) more structured approach (Creswell & Poth, 2018). Adherence to this framework dictates my data collection and analysis procedures.

It is important to note that in qualitative research, the researcher is itself an instrument through which to draw inference. While this is seen as something to minimize and control in quantitative methods, it is considered an important aspect in qualitative research. Where quantitative researchers are tasked to use valid and reliable tools to convey robust and replicable research, qualitative researchers are tasked with acknowledging their positionality and reflexivity to convey trustworthiness. In the next section, I provide context about experiences and beliefs that I bring with me into my research endeavors with the hope of providing a more holistic understanding of my research and how I've come to draw inference from it.

Positionality

First and foremost, I come at this project from the perspective of a student. As such, my own commitment to lifelong learning along with the education I've received in the Education Department has taught me to think about my project holistically. This entails trying to

understand the foundational concepts that support the overarching theoretical framework of my research. This extends beyond understanding existing links between concepts in adjacent fields to understanding the historical and cultural contexts in which such knowledge had arisen (Carson, 2002). Further, I was encouraged to and made a habit of drawing my own connections that were meaningful to me and that emerged from my existing knowledge and experience. I reflect a lot on my own learning process. The metacognitive awareness of the value of such practices (i.e., reflection, practice; Willingham, 2009) has not only led to a rich educational experience during my time at MSU but has enriched the quality of the research I conduct. This translates to a strong foundational understanding of important concepts, keen observational skills, and the ability to relate well with people and ideas. One of the ways this will manifest in my dissertation is in the occasional use of conceptual maps that help to make connections and visualize the relationships between important academic and real-world concepts.

While the topic of food-system sustainability is the focus of academic discussion throughout my dissertation, it becomes evident in Chapter Five that everyone makes sense of this concept in their own way. I have been engaged with the concept academically and personally for many years, starting in high school with discussions about environmental sustainability. I attended a regional magnet school for math and science where I gained early, direct experience with the scientific method. I have always loved biology and in high school and college I became increasingly curious about ecology. A college course sparked an interest in where my food came from and by the time I graduated I was working on a farm. This becomes important as I relate to undergraduate students during interviews and as I try to co-construct an understanding of a social process (learning about sustainability) from 20 student interviews. My own time reflecting on the

topic helped to establish rapport and lent depth to my analysis. The emergent conceptual model (Chapter 5, Figure 2) includes my own metacognitive take on how I understand the concept of sustainability.

Lastly, it is worth noting that a lack of connection to my ancestral culture, paired with the distrust I have in our current governing systems in America, have made me reexamine my core philosophical assumption through which I engage everyday life. I am now cognizant that I cannot separate my understanding of learning and teaching from spiritual and cultural contexts. Through coursework (EDU 557 Brain Science, Teaching Research, and Learning; EDU 610 Qualitative Research Methods) and cultural connections not associated with my research program, I became increasingly aware in the ways that culture frames our understanding of the world. Feeling culturally untethered, paired with alarming rates of cultural and environmental degradation, an influx of new academic concepts, and experience working cross culturally, prompted a deep examination of my own personal axiology, ontology, epistemology, and methodology. This becomes important to how I conceptualize solutions to current food-system issues.

The ideas that emerge from this dissertation validate many ideas that have emerged in academic contexts, yet the challenge remains to finding ways to apply ideas posited in dissertations to contexts grounded in real-world, lived experiences of everyday life. Further, we much challenge ourselves to reflect on how these ideas may suggest that our current models of inquiry, relating to one another, and problem-solving are no longer working. For change to occur, I believe we must radically reframe how we conceptualize progress. I'm aware that institutional education has many strengths in generating knowledge and solutions, as some of

them will be described in this document. But some of the most glaring weaknesses I notice lie in its fixed notions of progress that have emerged from colonial power structures and its unwillingness to integrate multicultural and indigenous perspectives into the dominant western perspective to enhance its problem-solving capacity. While this academic context might not seem an appropriate place to insert personal commentary, I find it my duty as a highly educated individual who has had the privileges I've had, to use my platform to give voice to those who don't have a seat at the table.

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CHAPTER TWO

LITERATURE REVIEW

Organic Soil Fertility

As agriculture has evolved to favor large scale systems of food production aimed at feeding a growing population, negative externalities have emerged as a result of how humans have managed agricultural lands. Specialization, mechanization, and the intensity with which food is produced has led to soil erosion, nutrient depletion, eutrophication of natural waters, and decoupling of major bio-geochemical processes (Magdoff & Van Es, 2009; Mitchell et al., 2019). While agriculture is a contributor to the current climate crisis and mismanagement of agricultural soils have contributed to the demise of previous societies (Montgomery, 2012), it also offers an avenue to potential solutions as holistic and reciprocal management of soil has been a cornerstone of indigenous societies that have lasted over millennia.

Soil is an important driver of agroecosystem processes (Magdoff & Van Es, 2009), and through its connection to biological systems across all scales, emergent behaviors arise from soil ecosystems that highlight the vastly complex and interconnected nature of soil (Lehman et al., 2020). Early pioneers of organic agriculture believed that changes in management practices were needed to support the long-term vitality of soil on which agriculture is dependent. This reflects a philosophical shift from feeding the plant to feeding the soil and led to an emphasis on soil biology as the foundation for healthy and functioning soils (Albrecht, 1938; Howard, 1940). Despite that recognition by early visionaries, most of our research and development of soil health concepts until late has revolved around chemical and physical indicators of soil health

(Karlen, 2012). Now that we have a robust understanding of soil biology's synergistic effects on overall soil and ecosystem health (Lehman et al., 2015), research in recent decades has focused on elucidating mechanistic understandings of biological processes in global and agricultural soil systems (Schimel & Bennett, 2004; Schmidt et al., 2011; Karlen, 2012; Lehmann & Kleber, 2015; Lehmann et al., 2020; Weng et al., 2021). As a result, soil organic matter (SOM), which can be defined as the fraction of the soil consists of plant or animal tissue in various stages of breakdown (Fenton et al., 2008), serves as a widely accepted indicator of biological, physical, and chemical functions in soil (Magdoff & Weil, 2004; Magdoff & Van Es, 2009). While it does not encapsulate all aspects of soil function, and should not be an absolute indicator of soil health, SOM, in conjunction with soil biota that it provides habitat and fuel for, imparts emergent behaviors that enhance plant growth and ecosystem function (Lehman et al., 2020; Lehman et al., 2015).

Many farmers embrace the concept of building soil organic matter (SOM) with a long-term goal of reducing the need for off-farm inputs. Despite its relatively low proportion of the overall soil volume, SOM has such a large influence on biological, chemical, and physical properties of soil that SOM content (%) alone is sometimes used as a proxy for soil health (Drinkwater & Snapp, 2007; Gaskell et al., 2000; Magdoff & Weil, 2004; Weil, 2004). As organic matter provides food and habitat for flora and fauna, organisms interact with the physical and chemical components of soil to mediate significant portions of global nutrient and water cycles (Abawi & Widmer, 2000). SOM also imparts disease and pest resistance through biologically mediated defense mechanisms (Schlatter et al., 2017). The host of positive

characteristics SOM imparts has led to an emphasis on SOM inputs to strengthen agroecosystem integrity.

Increasing organic matter in agricultural soils is shown to impart beneficial properties to the soil such as increasing aggregation and cation exchange capacity and stimulating biological activity which enhances nutrient cycling (Magdoff & Van Es, 2009; Magdoff & Weil, 2004). These are considered positive to overall soil quality and shifts in management prioritize the accumulation of organic matter. Yet, carbon sequestration in soil can be seen as a paradox because biological activity and subsequent nutrient cycling comes with the decomposition (loss) of organic matter (Bruce et al., 1990; Janzen, 2006; Lehman & Kleber, 2015). Janzen (2006) likens this tradeoff between building organic matter and its subsequent decomposition to a hydro-electric dam and reservoir, in which management must balance influx and outflux of water to maintain reservoir levels. Rather than highlighting soils capacity to store C indefinitely (a carbon 'sink'), Janzen (2006) proposes that soil should be viewed as a carbon 'tank', in which management optimizes the timing of decay to benefit crop needs, while maintaining or building organic matter stores to ensure that soils always have C to burn. It is in this dynamic nature of organic matter that its true value lies (Albrecht, 1938). Since both long-term organic matter stores and short-term nutrient mineralization are important to agricultural productivity, a balance between these two goals need to be achieved.

Bacteria and fungi are the largest contributors to SOM decomposition and processing (Scow, 1997). Decomposition may facilitate the addition (mineralization and desorption) or removal (immobilization and adsorption) of plant-available nutrients in the soil. Mineralization of SOM and desorption of inorganic nutrients occurs simultaneously with immobilization and

adsorption of inorganic nutrients, so the net availability of nutrients is dictated by the rate of each process.

Many factors influence the decomposition rate of organic materials in soil and subsequent nutrient availability to crops. Higher temperature and greater moisture content foster an environment where decomposition happens more rapidly, leading to active SOM pools mineralizing nutrients for crop uptake (Quemada & Cabrera, 1997; Stott et al., 1986). Similarly, the ratio of carbon to nitrogen (C:N) in organic amendments influences the rate in which soil nutrients are mineralized or immobilized. Generally in agricultural settings, materials and residues with a higher C:N (>30) are associated with nutrient immobilization and SOM accumulation, while materials with lower C:N (<20) are associated with greater rates of nutrient mineralization (Schroth & Sinclair, 2003). Different forms of nitrogen in SOM also influence availability to crops, ranging from more labile amino acids to recalcitrant forms bound in aromatic structures (Seiter & Horwath, 2004). However, Schmidt et al. describe how these preferential models do not hold true if the right conditions and microbial communities are present (2011). Yet in applied settings, studies show how the form of N, specifically whether it's stabilized in organic compounds or in soluble forms, drive it's release into plant available forms more than C:N alone (Gale et al., 2006; Marshall et al., 2016)

The mechanisms (described above) though which decomposition occurs informs how we manage our agricultural soils. Soil biology mediates physical and chemical processes and SOM mediates soil biology through provision of habitat and fuel (Seiter & Horwath, 2004). Knowing where to focus attention (soil biology) is necessary for our capacity to conceive agriculture's role in creating solutions to current crises. Yet, there exist considerable gaps in our mechanistic

understanding of biological processes and how management affects these. In recent challenges to our traditional understanding of SOM persistence and nitrogen (N) mineralization dynamics, scholars describe how environmental and management conditions that increase the functional complexity of SOM (molecular diversity, spatial heterogeneity, and temporal variability) are more important drivers of nutrient cycling than the presence of specific organisms or compounds in the soil (Lehman et al., 2020; Lehman & Kleber, 2015 ; Schimel & Bennett, 2004; Schmidt et al., 2011; Weng et al., 2021). Due to the challenges of studying soil *in situ* and the uncertainty of our conceptual models, it is hard to appropriately apply these emerging academic concepts to applied land management settings. Due to this uncertainty, for organic material to be applied with nutrient provision and soil quality improvement goals, our best suggestion is to minimally disturb soils and treat them with a diversity of amendments, which will promote molecular diversity, spatial heterogeneity, and temporal variability. These strategies promote conditions which ultimately lead to biodiverse microbial communities.

In organic systems, ensuring soil fertility is more complex and nuanced than replacing nutrients removed by crop harvest with soluble fertilizer salts, because different types of organic amendments and compost products vary in their nutrient composition. Conventional producers have access to cheaper and more concentrated sources of N than organic producers do. Due to the many interacting factors influencing decomposition rates and nutrient cycling of organic amendments, consensus on best practices in organic fertility management is elusive. Soil and foliar tests can determine nutritional needs and inform decision making; however, producers often need help to interpret results and implement appropriate treatments. Gaining a better understanding of how organic amendments contribute to crop needs and overall soil quality will

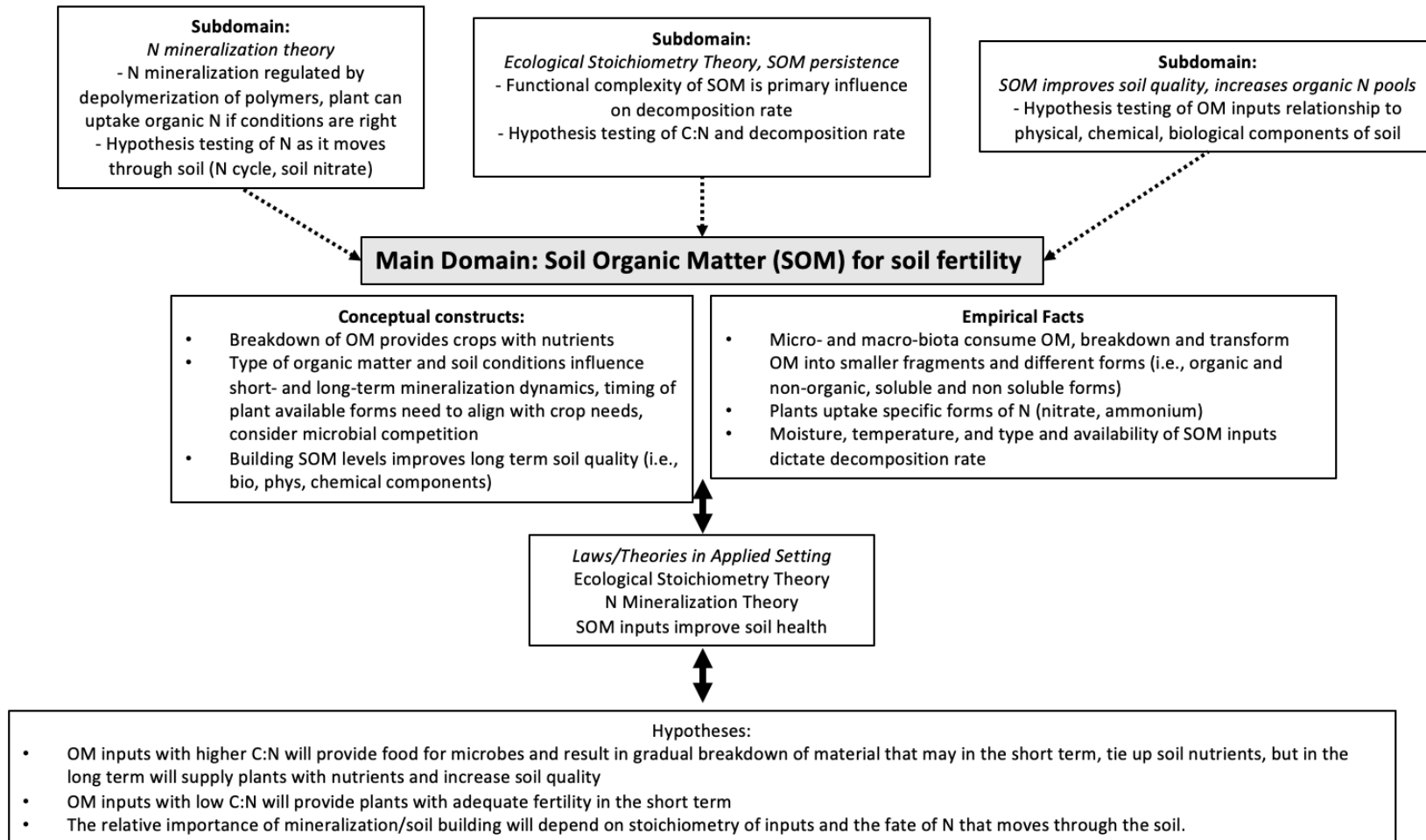
assist vegetable growers with fertility management practices, including amendment selection, interpretation of soil testing, and timing and quantity of application.

Irrigated small farms and diversified organic vegetable farms are increasingly important to the economy and landscape ecology of Montana, which is one of the leading states in the country in local food production and consumption (Strolling of the Heifers, 2019). These farms are characterized by high levels of revenue per acre offset by high labor costs and a reluctant reliance on tillage. Using season extension techniques such as high tunnels are particularly important in Montana and other northern climates due the short growing season. Ensuring long term soil productivity is important in high tunnel settings because they have the capacity to support higher cropping intensities. The increased intensity places extraordinary demands on the soil and can exhaust its nutrient resources more quickly than field crops. Optimizing fertility management in these settings is important to the ability of producers to make best use of sunlight and the limited growing degree days available to them.

The stoichiometry of organic inputs, in this case referring to C:N, influences decomposition rates and N mineralization patterns, but how this affects short- and long-term soil quality and crop performance in a quantifiable way requires further research. Since building SOM and providing crops with nutrients in organic settings are often seen at odds with each other, it is not understood where the optimal balance between these two phenomena lie, especially within the intensive high-tunnel system. Conceptually, our goal is to begin managing soil fertility based on an understanding of *when* nutrients are being mineralized or immobilized, not on the quantity of inputs alone. Practically, however, given our limited capacity to predict nutrient cycling mechanisms, we still rely on proxies of mineralization dynamics such as C:N, N

concentration, and what form N takes in amendments to make management decisions. Therefore, the goal of the research presented in Chapter Three was to determine where the optimal C:N range of organic amendments lies to achieve adequate crop yield. We hypothesized that inputs with higher C:N will have lower yields initially, while inputs with lower C:N will support immediate production goals. Below is a conceptual model that supports the theoretical basis of this research (Figure 1).

Figure 1. Graphical model of the conceptual components of my soil research.



In Support of Active Learning

Evidence from learning sciences, cognitive psychology, and educational psychology suggest that students learn better by doing and retain more information when actively engaged in the processing of new information (Ismail & Groccia, 2018; McKeachie & Svinicki, 2014; Michael, 2006), especially in STEM disciplines (Burrows & Slater, 2015; Freeman et al., 2014; Fairweather, 2008; Kelley & Knowles, 2016; Labovet et al., 2009) and applied fields such as agriculture (Ahmed et al., 2017; Andrée et al., 2016; Hilimere et al., 2016; Jachowski et al., 2022; Jacobson & Wilensky, 2006; Jordan et al., 2014; Valley et al., 2018). Actively engaging students in the learning process is more effective than traditional passive approaches specifically because it is more likely to affect a students' cognitive, psychomotor, and affective learning domains (Ismail & Groccia, 2018; Bloom et al., 1956). To this end, engaging students in higher-order cognitive strategies, providing multiple contexts and settings to process information while using peer interaction, and having students reflect on their experiences will maximize their potential for intellectual growth (Ismail & Groccia, 2018; Miller, 2011; Slavich & Zimbardo, 2012; Smith et al., 2009). Essentially, we need to provide more opportunities for students to demonstrate their understanding and receive feedback. The best way to prepare our diverse student body to be effective problem solvers in organic agriculture is to provide them with curriculum that integrates contemporary learning theory and serves the needs of diverse learning styles.

Learning-centered (or student-centered) teaching and learning

The shift from a teaching paradigm to a learning paradigm has paved the way for the university system to address systematic shortcomings to the college experience (Barr & Tagg,

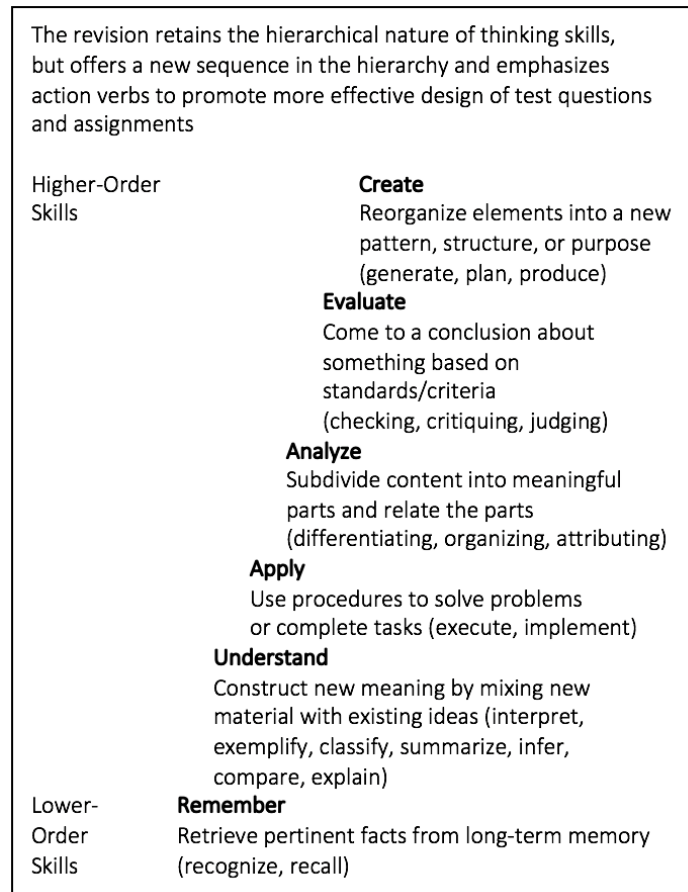
1995). The framework of the teaching paradigm prioritizes the delivery of instruction and sidelines accountability for student learning. A shift to a learning paradigm redefines an institutions responsibility to produce learning rather than just provide instruction. As Barr and Tagg (1995) point out, the traditional institutional framework mistakes a means for an end. The means – teaching – should not be an end goal, rather, it should be a means to achieve student learning using whatever approach works best. This shift not only prompts a reevaluation of effective ways to promote student learning (ex. by means of mode of delivery), but also encompasses a paradigmatic shift in that the institution itself is a *learner*. This means that it engages in a flexible and evaluative feedback process that continuously learns how to produce more learning over time through adaptation and adjustment, “continuously modifying one’s behavior to better achieve the goals” (Barr & Tagg, 1995). In practice, ensuring delivery of content is not enough but rather responsibility needs to be taken for student learning.

While students must take responsibility for their own learning, the existing institutional structure and framework setting the foundation for teaching and learning must be critically evaluated. There is research showing that the dominant lecture approach to content delivery is not the most effective way to engage students (Slavich & Zimbardo, 2012). The basis for enhancing active engagement with content material is based on constructivist learning theory which suggests that students learn by making meaning of their experiences (Lord 1997; Piaget 1926, Vygotsky, 1978). Designing curriculum and pedagogy using active learning and student-centered learning principles facilitate deeper learning in students versus lecture styles that engage students with concepts more passively (Ishmail & Groccia, 2018). Instructional methods utilizing collaborative learning, experiential learning, and problem-based learning get at the heart of

constructivist learning theory by encouraging students to make meaning from direct experiences and using them to contextualize and process new ideas and information (Slavich and Zimbardo, 2012). While these principles and methods have nuances in implementation, they all share constructivist roots and the notion that students “learn better by doing,” (Slavich and Zimbardo, 2012, p. 575). Student-centered approaches aim to engage the affective domain of students. Slavich and Zimbardo (2012) postulate that student-centered principles that emphasizes content mastery and positive learning related attitudes constitute an approach to classroom instruction called transformational teaching. By having students build dynamic relationships between other students, teachers, themselves, and content, they engage more deeply and retain information more readily (Quinlan, 2016). Student-centered principles define the framework that encourages teaching to be adaptive and in service of the student (Barr & Tagg, 1995), while active learning principles define the ways in which we activate student learning; through reading, writing, discussion, and other modes of engagement (Slavich & Zimbardo, 2012).

Bloom’s taxonomy still serves as the foundational framework used to define levels of thinking. He organizes thinking skills based on increasing complexity, distinguishing between lower versus higher order skills. This framework is important in helping instructors outline the types and level of thinking that would satisfy course learning objectives. However, Krathwohl and Anderson (2001) have revised this framework and replaced the nouns with verbs to give the terms more utility for assessing measurable objectives (Figure 2). This revision also positions “create” as the highest level of thinking (formerly evaluate) to emphasize the goal of students becoming independent thinkers and creators of knowledge.

Figure 2. Krathwohl and Anderson's (2001) Revision of Bloom's Taxonomy (Adapted from Svinicki & McKeachie, 2014).



Learning is social

Another pillar of student learning theory that supports the need for curriculum reform is the role that group-learning plays in student success. Promoting collaborative discovery through peer interaction rests on the idea that “learning occurs best when done in groups,” creating a more dynamic and motivating learning environment by fostering a sense of responsibility for their own and peers’ learning (Brown, 2008; Johnson & Johnson, 1974; Slavich & Zimbardo, 2012; Slavin, 1995, 1977; Svinivki & McKeachie, 2011). Building on the constructivist notion that students learn by making meaning and situating their new experiences in their old ones,

social constructivism purports that learning is further shaped by their historical, social, and cultural context thereby making social interaction influential to their educational experience (Bruner & Haste, 2010; Vygotsky, 1978, 1986). Synthesizing, summarizing, and communicating personal understanding to peers help students restructure knowledge and create cognitive bridges to other ideas or concepts. Having practice with this also develops problem solving skills and positions social modelling as an integral part of the student experience (Smith et al., 2009).

Peter Jarvis (2018) captures the deeply personal and social dynamic of experiential learning. His work stems from his belief that Kolb's Experiential Learning Cycle model oversimplifies the social nature of learning. In essence, his understanding of learning is both experiential and existential. Learning is existential when we have a sensation or disjunction which appears to have no meaning and only our introspective self to make sense of it. This is indicative of early stages of learning. Over time, the meaning we ascribe through our own sense-making starts to occur in a social context, in which solutions to subsequent disjuncture become social constructs (experiential). Over time, our experiences lend themselves to the creation of categories or patterns in which humans can more efficiently make sense of things by relating to past experiences and lessons. These frameworks in which learning processes operate are a crucial part of how we understand what it means to be a member of society.

Learning on Campus Farms

Foundations in Experiential Learning Theory

Parallel to the evidence that has accumulated in support of active learning principles, campus farms provide valuable learning environments for students (Sayre & Clark, 2011). The value of learning on campus farms rests primarily in experiential learning. When opportunities

for concrete experience are integrated with other modes of learning, outcomes are enhanced (Kolb, 2014). Traditional conceptions of Experiential Learning Theory (ELT) stem from David Kolb's 1984 work which builds upon pragmatic interpretations of learning put forth in the 20th century from western philosophy, psychology, and sociology. In this section, I discuss the foundations of ELT to more acutely capture nuances of the social context of learning as it relates to learning on campus farms.

David Kolb (2014) defines ELT as, "the process whereby knowledge is created through the transformation of experience... Knowledge results from the combination of grasping and transforming experience," (p. 41). His contributions to ELT are paramount and draw primarily on the works of John Dewey, Kurt Lewin, and Jean Piaget, who each emphasized experience as central to learning and whose work will be briefly discussed in this section. The culmination of these works into what we now refer to as ELT challenged traditional educational approaches that favored cognition and objective observation over the role of one's affect and subjective personal experience in learning (Kolb, 2014).

John Dewey is perhaps the most influential educational philosopher of the 20th century. His pragmatic approach to philosophy placed an individual's agency at the center of learning. He recognized that the dynamic nature of personal experience is instrumental in how we make sense of the world. In Dewey's pragmatism, one cannot know the world separate from their experience of it. Promulgation of these ideas challenged the rationalist philosophy that accepted dissonance between experience and theory in favor of upholding an absolute truth that exists beyond human interference (Kolb, 2014). For Dewey, it was more important be engaged on a personal level than to remain in theoretical realms. Due to these philosophical leanings, learning could not be

discussed without mention of the social context in which it took place. He described learning as part of a larger democratic process characterized by self-directed inquiry. Learning not only developed the individual but took place on a social level with an interdependent sense of societal progress as a goal.

Kurt Lewin was an applied social psychologist who researched group dynamics. From his work emerged another case for the importance of the social context in which learning occurred. He was not afraid to let intuition guide his research methodology as he developed novel approaches to understanding group change. His observation of dialogue between researchers and subjects led to an understanding that tension between concrete experience and abstract concepts served as an impetus for deep learning moments. The importance of tension between experience and analytic detachment separated his notions of learning from predominant philosophical and psychological notions that learning happens to an “empty vessel” and is an impersonal and detached process (Kolb, 2014). From Lewin’s work emerged practical insights on the phenomenon of human behavioral change in organizational settings.

Jean Piaget mounted more of an internal challenge to rationalism through his work on cognitive development processes in children (Kolb, 2014). Initially designed within an objective observational framework, Piaget’s studies led to the perception that learning was qualitatively different for different aged children. His shift from measuring levels of intelligence in children to investigating their process of reasoning led to a discovery that intelligence itself is primarily shaped by experience. By seeking to explain intelligence as opposed to understand or quantify it, Piaget formed notions of cognitive constructivism that positioned an individual’s own agency in making sense of the world at the center of cognitive development.

It is through a brief description of the contributions of these three men that we can better understand how David Kolb came to develop a formal theory (ELT). Kolb emphasized the transformative nature of personal experience. Kolb and his three predecessors did not presume experience to be the means and end of learning itself, but rather that it serves as a compliment to other approaches in teaching and learning. It is in conjunction with reflective observation, abstract conceptualization, and active experimentation that concrete experience can be transformative (Kolb, 1984). The value of ELT lies in its transformative power- its capacity to change a person and enrich their worldview to a position of more experience, where it then serves as the foundation for more learning.

Radical Education for cultural survival and critical consciousness

Radical educators Paulo Freire (1970, 1974) and Ivan Illich (1970) influenced ELT with their focus on the social context of learning as a means of individual and community empowerment. Their major critique of traditional education systems is exemplified in Freire's (1970) banking model of education, a metaphor he used to portray students as banks in which educators made deposits of knowledge. In this model, Freire (1970) describes how current educational models have succumb to "narration sickness," where the process of institutional learning has become passive and lifeless (p. 71). The works of these men situate learning as a means to uplift people and overcome oppression. Acknowledging and centering inequity and systemic oppression, Freire and Illich describe how education has the potential to be a force of empowerment if harnessed to confront and resolve disjuncture in people's lives. According to them, current education models do not promote critical thinking and are characterized by a top-down authoritative apparatus that reinforces capitalist measures of progress at the expense of

well-being for the majority. Further, obligatory, didactic, and segregated spheres of education do more to uphold existing power structures than they do to uplift community well-being and encourage intellectual growth. They saw the need for educational structures that encourage what Freire (1970) called “critical consciousness,” a process whereby people actively discover conflict and generate solutions in socially appropriate contexts that utilize unconventional methods of instruction and learning. While these scholars influenced Kolb’s conception of ELT, their notions of developing a critical consciousness among citizens deserves more of a central role in the conception of experiential learning because student farms provide a space for learning to occur settings where power structures aren’t as readily visible and where students are encouraged to identify and reflect on disjuncture they notice between their conceptual understanding of sustainability and their experiences on a farm.

Gestalt Psychology

Another foundation of ELT is the conception and articulation of Gestalt Psychology. Developed in the early twentieth century by Wertheimer, Köhler, and Koffka, gestalt psychology refers to the tendency of our mind to perceive a set of seemingly disparate sensations or concepts as a meaningful whole (Hunt, 1993). Essentially, gestalt psychology asserts that we perceive in patterns, not individual components. Wertheimer suggested that Gestalt theory explains more than mental and visual perception; it extends insight into the keys of learning, motivation, and thinking (Hunt, 1993). The same parts of our brain that organize visual stimuli also organize our thinking (Carson, 2017/2003), so the importance of Gestalt psychology extends beyond autonomic tricks-of-the-mind with implications for the way our minds seek to develop and utilize patterns in our thinking. The link I see between Gestalt psychology, ELT, and learning on

campus farms is the role that personal experience plays as a grand unifier. Our personal concrete experiences have the capacity to connect dots between knowledge we've gained through reflective observation, abstract conceptualization, and active experimentation. Our minds organize personal experiences into patterns that allow us to connect seemingly disparate concepts. In the absence of personal experience, these connections are made less effectively and efficiently. (I would say it is impossible to "lack" personal experience- rather this suggests that teachers have a role in designing learning opportunities from diverse and enriching experiences)

Revisiting the connect-the-dots analogy: concrete experience provides the learner with dots to clarify the underlying pattern at play. I would even go as far to say that "dots" associated with experience hold more integral positions than dots associated with reflection, abstraction, or experimentation. In the learning context, personal experiences can connect previously unrelated subtopics into cohesive, unifying images or ideas that have a greater meaning when viewed in relationship.

To support these claims, Quinlan (2016) emphasizes this idea that learning is enhanced when relationships between the learner and subject matter, teachers, peers, and themselves are developed. Giving students the time and space to foster these relationships through utilizing a diversity of modes of engagement (including experience) encourages new information to fit more readily into the scaffolding of their minds. As teachers, we must take advantage of the mind's tendency to use patterns and the transformative nature of personal experience to introduce order to ambiguous situations (Carson, 2017/2003).

To relate it to Piaget's notion of *assimilation* and *accommodation* in cognitive development, the human mind is extraordinarily effective at using gestalts to process information

by organizing, connecting, and restructuring it in a way that promotes meaning (Carson, 2002; Kurfiss, 1994). It is increasingly evident that a reliable way to prompt this restructuring of information into meaningful ways is through personal experience. Essentially, ELT is valuable insofar that varying modes of engagement (including experience) takes advantage of our mind's tendency to make connections.

Vygotsky

I would be remiss not to discuss the works of Lev Vygotsky when discussing the importance of experience and social context in the learning process. Vygotsky brings to us a deeper understanding of social constructivism and how we use tools to mediate thought. Again, we see an emphasis on the cultural and social context from which these cognitive tools emerge and how human intelligence is a product of engaging with these tools. Lev ensures us that learning is not a passive process. In fact, finding meaning from the relationship between mind, culture, language, and thought is fuel for cognition. He convinces us that cultural understanding is built upon our use of cognitive tools made of symbols and gestalts, and vice versa. His teachings describe a co-evolution of culture and consciousness (Carson, 2016). The importance of this notion is amplified by Freire and Illich who argue that learning cannot be separated from everyday life and that learning in educational institutions is too abstract to be meaningful. They see more value in models that center vocational learning and skill development and are run by teachers who are still actively practicing their vocation. The implications of this, in accordance with Vygotsky's work, means that culture and societal well-being should be cultivated on a grass-roots level as opposed to a top-down, authoritative one.

The lens that Vygotsky puts forth is enriching. He is one of the first to suggest the central role that the cultural development of semiotic systems play in enabling our increasingly complex cognitive apparatus (Carson, 2016/2003). Situating conceptual development in a cultural problem space (i.e., systems of mathematics arising from the need to count sheep) and seeing how its co-evolution with human consciousness has allowed us to develop mathematics into a truly complex and remarkable cultural subject is but one example of Vygotsky's intellectual contribution to ELT. As we continue to develop and use more sophisticated cultural tools to mediate thinking, we literally create new ways for us to experience life (Carson, 2016/2003).

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CHAPTER THREE

CARBON TO NITROGEN RATIO OF SOIL AMENDMENT IS A GOOD PREDICTOR OF
YIELD AND SOIL N IN TWO HIGH TUNNEL SYSTEMS IN MONTANA

Contribution of Author and Co-Authors

Manuscript in Chapter Three

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Contributions: I conceived the study, obtained funding, collected and analyzed data, and wrote and revised the manuscript.

Co-Author: Zach Miller

Contributions: Oversaw replicate research site. Mentored first author with experimental design and data analysis and interpretation. Assisted with editing and revising all sections of manuscript.

Co-Author: Mac Burgess

Contributions: Obtained funding. Mentored first author with all parts of conception, implementation, and communication of this research and manuscript.

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Carbon to Nitrogen Ratio of Soil Amendment is Good Predictor of Yield and Soil N in two High Tunnel Systems in Montana

Additional Index Words. *Lycopersicum solanum*, *Cucumis sativus*, mineralization, organic matter, vegetables, fertility

Abstract

High tunnels serve as important season extension structures and profit centers for northern vegetable growers who are limited by short seasons, cool nighttime temperatures, and limited growing degree day accumulation. In organic settings, where soil fertility is challenging to manage, we studied the effects of soil amendments with different C:N on tomato and cucumber yields in two high tunnel systems in Montana. We utilized a split-plot design with whole plots arranged in randomized complete blocks. Blood meal and soy pellet plots were the only ones to yield higher than unamended control plots, while plots that were amended with chicken or cow manure compost did not ($p=0.03$). Treatment effects on soil nitrate were stronger than they were on yield as all treatment plots had higher levels of soil nitrate than control plots, and the amendments with lower C:N had higher levels of soil nitrate. We suggest that farmers utilize amendments with low C:N for immediate crop nutritional needs and yield formation, yet we acknowledge the importance of applying compost products with higher C:N for the purpose of building SOM, as our control plots did not yield lower than compost plots, likely due to inherently high SOM in our study plots.

Introduction

In 2020, organic food sales increased 12.8%, representing the highest growth rate in over a decade (Shahbandeh 2022). While a large portion of these sales (~97%) are from operations with >\$100,000 in sales (US Department of Agriculture, National Agricultural Statistics Service 2019), small diverse organic vegetable farms are increasingly important to local food economies, especially in rural settings (Strolling of the Heifers 2019). The demand for locally grown organic produce supports a burgeoning farmers market and community supported agriculture (CSA) market sector. Organic vegetable growers in the Northern US have cooler and shorter growing seasons that are not conducive to growing crops like tomatoes and cucumbers in the field.

Season extension tools such as high tunnels are particularly important in northern climates due to short growing seasons, cool nighttime temperatures, and limited growing degree days (Carey et al. 2009; Montri and Biernbaum 2009). They are profit centers as the warm microclimate offers farmers the capacity to extend the shoulder seasons and to produce high-revenue crops such as tomatoes, cucumbers, and peppers that struggle to mature outdoors in cooler regions. Because high tunnels are important in generating revenue, they are cropped more intensely than field settings, with farmers getting two to three crops per year in one location. The increased intensity places extraordinary demands on the soil.

Farmers often fertilize without adequate understanding of the N mineralization dynamics of existing SOM, fertility amendments, or the legacy of past applications. This can lead to under fertilization which may limit crop yield, or over fertilization, which can lead to other soil-related management challenges. These include increased salinity, nutrient uptake antagonism from excess P and K, downstream environmental concerns from excess N and P, or just wasted money

on unnecessary inputs (Knewston et al. 2010; Montri and Biernbaum, 2009). This research arises from the need for farmers to optimize soil fertility within the unique climatic constraints of northern latitude vegetable growers.

In organic systems, ensuring soil fertility is more complex and nuanced than replacing nutrients removed by crop harvest with soluble fertilizer salts, because different types of organic amendments and compost products vary in their nutrient composition. This matters because nutrients applied in the form of organic amendments are not readily available to plants and must be broken down and released by microbes in the soil. Since conventional producers have access to cheaper and more concentrated sources of N, N is the most limiting factor to crop growth in organic settings. Gaining a better understanding of how organic amendments contribute to crop needs and overall soil quality will assist vegetable growers with fertility management practices, including amendment selection, interpretation of soil testing, and timing and quantity of application.

Temperature and moisture are the primary drivers of microbial activity, with increases in both leading to active SOM pools mineralizing nutrients for crop uptake (Quemada and Cabrera 1997; Stott et al. 1986). Amendment composition also influences mineralization dynamics because they typically vary in levels of macro- and micronutrients that come in both organic and inorganic forms. Fertilizers made from the by-products of the animal slaughtering industry typically contain the highest concentration of N (~13-14% N; i.e., blood or feather meal), while various commercial and homemade composts with lower N concentrations (~1-3%N) are also commonly used.

The ratio of carbon to nitrogen (C:N) in organic amendments influences the rate at which soil nutrients are mineralized or immobilized (Guster 2005). Materials and residues with a higher C:N (>30) are associated with nutrient immobilization and SOM accumulation, while materials with lower C:N (<30) are associated with nutrient mineralization (Schroth and Sinclair 2003). Different forms of inorganic and organic nitrogen in amendments/SOM also influence availability to crops, ranging from soluble forms of inorganic N (e.g., ammonium) and labile amino acids to recalcitrant forms bound in aromatic structures (e.g., lignin, cellulose; Seiter and Horwath 2004). Amendments with higher concentrations of readily available inorganic N, such as blood meal, are reported to release most of their N (~60%) within the first 30 days of incorporation, while compost amendments with higher concentrations of organic N (as opposed to inorganic N) have a slower and steadier pattern of N release (Gale et al., 2006; Hartz and Johnstone 2006). In a Maine study investigating the effects of different compost products on crop yield and N mineralization rates, Marshall et al. (2016) demonstrated that inorganic N is a more accurate predictor of short-term yield of tomatoes than total N at application. While this suggests that N-rich amendments affect short-term yield, there is evidence that long term compost applications lead to an enriched organic soil N pool with better utilization dynamics (Guster et al. 2005; Seiter and Horwath 2004).

Organic farmers utilizing high tunnels are tasked with having to supply high-value, heavy-feeding crops with an adequate nutrient supply while also ensuring long-term soil productivity through the enhancement of the soil organic N pool. Long-term N mineralization is not just important annually, but also for duration within the growing season as indeterminate trellised crops such as tomatoes and cucumbers that are harvested for up to 12 weeks. These

goals are usually approached using different means, but since both long-term organic matter stores and short-term nutrient mineralization are important to agricultural productivity, a balance between these two goals needs to be achieved.

While there exist general predictors of N mineralization dynamics, such as moisture, temperature, and amendment stoichiometry, managing soil fertility to balance short- and long-term goals is inherently challenging. This challenge is amplified for organic high-tunnel growers in northern climates where crop nutrient demands are higher and mineralization conditions are altered (Montri and Biernbaum, 2009), and there lacks specific research or extension material to guide decision making processes in these settings.

The purpose of our study was to test whether amendment composition (C:N ratio) remains a good predictor of soil N and crop yield in two high tunnel settings in Montana, and to see whether the timing of N release differed amongst a variety of soil fertility treatments. The specific objectives of our study were to identify which organic soil fertility amendment, selected in a range of C:N, 1) supports the highest total annual high-tunnel yields, 2) supports the highest early season high-tunnel yields, and 3) sustains adequate levels of soil nitrate over the duration of the growing season. Gaining a better understanding of how organic amendments contribute to crop needs will assist vegetable growers with fertility management practices that satisfy both short- and long-term goals.

Materials and Methods

Site Description

This experiment was conducted over two growing seasons from May 2020 to October 2021 at two sites in Montana: Montana State University's (MSU) Horticulture Farm in Bozeman,

MT (45.665115°, -111.072510°; elevation 4,793 ft); and MSU's Western Agricultural Research Center in Corvallis, MT (46.328309°, -114.084123°; elevation 3,481 ft). The sites differed in climatic conditions, soil types, and high tunnel construction characteristics (Table 1). Bozeman soils are Turner loam and in 2015 the site received a large input of composted manure. Bozeman high tunnels were double cropped in the three seasons leading up to our experiment, with either spring or fall carrots, spinach, and beets in addition to summer tomatoes and cucumbers, and single cropped throughout the duration of the experiment. Corvallis soils are Burnt Fork loam and are sandier with lower levels of OM. Corvallis tunnels were cropped less intensely than Bozeman prior to the commencement of this study, with only one crop grown per year (tomatoes).

Experimental Design

Plots were arranged in a split-plot design with 3 replicate blocks at each study site. Bozeman's study site consisted of three high tunnels that each represented a complete block. Corvallis' study site consisted of one high tunnel with three complete blocks within the single high tunnel. The whole plot factor was organic fertility amendment as it was harder to vary without edge effects, and the split plot factor was crop (tomatoes or cucumbers). The whole-plots were 50 sq ft in Bozeman and 40 sq ft in Corvallis. Tomato and Cucumber were rotated within split plots from 2020-2021. Organic soil fertility treatments consisted of 1) blood meal; 2) soy pellets, 3) chicken manure compost; 4) cow manure compost; 5) 2x rate of cow manure compost applied only in year 1; and 6) an unamended control (listed in order of descending N concentration; Table 2). The cow manure compost treatment was a commercially available bagged product made from anaerobically digested dairy manure and bedding. Blood meal and

soy pellets were considered to have low C:N, while all animal manure fertilizers (chicken manure, cow manure, and 2x rate of cow manure compost) were considered to have high C:N for the sake of this study. Organic soil amendments were applied at rates resulting in total N application of $14 \text{ g} \cdot \text{m}^{-2}$ (125 bs N / acre), except for the unamended control and the plot with two-times the rate of cow manure compost, which was applied at the rate of $28 \text{ g} \cdot \text{m}^{-2}$ (250 lbs N / acre; Marshall et al. 2016), which mimicked the common practice of applying compost in high tunnels every other year. Whole plots were randomized during establishment and reamended with the same treatment the second year. Crop type was reversed the second year to maintain common crop rotation practices.

Site Management

Both crops were started in MSU's Plant Growth Center until ready for transplant. Seeds were sown into Promix MP Mycorrhizae Organik (Premier Tech Horticulture, Quakertown PA), which is a peat based Organic Materials Review Institute (OMRI) listed potting mix. Tomatoes were sown in rows of 15 in 20 row flats for two weeks then transplanted to 4.5" pots and were fertilized with 5-1-1 fish emulsion twice a week. The cultivar Citrine (F1) cherry tomato [*Solanum lycopersicum*] was grown in Bozeman and Sun Gold (F1) cherry tomato was grown in Corvallis (Johnny's Selected Seeds). The cucumber cultivar Corinto (F1) [*Cucumis sativus*] was used at both sites and sown in 6-pack trays (Johnny's Selected Seeds). Crops were transplanted into high tunnels approximately one to two weeks before the 30% last spring frost date for a given location, given that the ten-day forecast did not include frost. This was May 18-25 in Corvallis and May 25-June 2 in Bozeman. Tomatoes were approximately 8-18 inches in height and cucumbers had developed their first true leaf by the time transplanting occurred. Prior to

transplanting, tomatoes and cucumbers were transported to Corvallis for hardening off and transplanting. High tunnels were prepared by weeding and rototilling soil. Organic soil fertility treatments were applied approximately one week prior to transplant and rototilled to incorporate fertilizers and prepare beds for planting. Black plastic mulch and drip tape with 12-inch emitter spacing and 0.34-0.56 GPH flow rate were laid prior to planting. Within each fertilizer treatment, one row of each crop was planted. The Bozeman site was planted with 10 plants of each crop per fertilizer treatment plot and Corvallis was planted with 8 plants of each crop per fertilizer treatment plot. Crops were planted with 12 inch spacing between plants, offset by 12 inches, with 18 inches between each whole plot. Each block was planted in a single day, and in the instance that a site could not be completely planted in one day, planting occurred on consecutive days. Crops were irrigated three times per week for the first 2 weeks to encourage establishment then watered two times per week after that. Each week crops were irrigated with approximately 1.5 inches of water per week. Cucumbers and tomatoes were pruned to one leader and trellised approximately five times throughout the growing season by two trained staff at each site.

In Bozeman, high tunnel ventilation was controlled by automatic end wall vents (approx. 1 m²) and manual sidewall rollers up to 4ft. Until nighttime temperatures were consistently above 50°F, sidewalls were lowered each evening. Once temperatures were consistently warm (starting approx. late June), sidewalls were left up all season. In Corvallis, ventilation was controlled by automatic end wall vents and automatic sidewall rollers set at a threshold temperature of 85°F.

Tomato and Cucumber Harvest

Cucumber harvest commenced once fruit reached 7-8 inches in size, as recommended by the supplier. Subsequent harvest events occurred as fruit reached the desired harvest size. This began late June and occurred two to three times a week, with three harvest events per week occurring during high temperatures when plant growth and fruit development peaked. Similarly, tomatoes were harvested two to three times per week, starting mid-July. Harvest events that occurred prior to market days (Monday through Wednesday) were harvested when fruit was light orange (stage 5), and harvest events that occurred on a Thursday or Friday included collection of fruit that were less mature and only starting to turn color (stage 3-4) (Saini et al. 2017). Diseased and damaged plants (e.g., pest damage, pruning injury) were flagged and subsequently excluded from harvest events to ensure yield data represented healthy plants. Due to removal of damaged plants throughout the growing season, cumulative yield was analyzed on a per plant basis. Protocols were established to ensure consistency across sites.

Soil Sampling and Nitrate Analysis

Soil samples were collected as composites of three sub samples on the whole plot level bi-weekly throughout the experiment. Samples were taken with an AMS probe with a 22mm diameter at a six-inch depth at a randomly chosen location within 12 inches of the bed center. Soil was analyzed for N (nitrate) only, except for the first sampling event for which N-P-K, pH, and OM (%) analysis was done to establish baseline soil characteristics (Table 1). All soil samples were sent to Agvise Laboratories in Northwood, ND for analysis.

Statistical Analysis

Total annual yield per plant data were analyzed across all site-years as a split plot design with organic fertility amendment as a whole plot factor and crop type as a subplot factor.

Location, year, and block were modeled as random effects. Year was treated as a split-split plot factor to account for repeated measures. The raw data violated ANOVA assumptions (homogeneity of variance) so models were run using log transformed data. Reported means were back transformed for ease of interpretation.

To determine whether treatment effects exhibited seasonal trends (e.g., earlier yields), total annual yield per plant data were also analyzed across sites but separately for each year. Years were analyzed separately to effectively nest different seasonal timeframes within a single year while accounting for the fact that total yield per plant for each time frame represented repeated measures. Timeframes consisted of early season (June and July), mid-season (August), and late season (September and October). This analysis served to specifically test whether any treatments provided an early season yield boost, as low C:N amendments have rapid N mineralization patterns compared to high C:N amendments, and tomato and cucumbers often receive price premiums in early season markets. Observing late season yield dynamics could also imply important temporal yield trends that may correspond to nitrogen mineralization dynamics with different organic amendments. No data transformations were necessary in this analysis as ANOVA assumptions were met and no outliers existed.

Soil nitrate N data were also analyzed with organic fertility amendment as a whole plot factor and year as a subplot factor. To explore how soil N levels differed throughout the season, sampling dates were organized categorically as month (early June, late June, early July, etc.) and nested as a split-split plot factor to account for repeated measures. Outliers persisted even with

data transformation, so three outliers were replaced with average soil N values from other corresponding blocks of that treatment combination.

Analysis of variance (ANOVA) was conducted in RStudio using the R package “agricolae” (Mendiburu 2021) and “car” (R Core Team 2022). P-values below 0.05 were considered significant. Post-hoc means separation tests were determined using Fisher’s LSD. While this increases experiment-wise error rates, it is commonly used in applied agricultural research studies that are more concerned with comparison-wise error, as the individual comparisons are the conceptual units of interest (Cramer and Walker 1982).

Results

Crop Yield

Overall, the total annual yield per plant differed for treatments, crops, locations, and years and met realistic production quantities given the system characteristics (Warren et al. 2015). The total annual yield per plant for both site-years was 4.75 kg per plant for cucumbers and 2.35 kg per plant for tomatoes, with Corvallis crops yielding higher than Bozeman crops by 40% and higher yields in the first year of the study compared to the second. Location and crop effects on total annual yield per plant varied by year. In Corvallis, yields were higher in 2020 than in 2021, while Bozeman crop yields did not differ year to year. Similarly, cucumber yields were higher in 2020 than in 2021, while tomato yields did not differ year to year.

Organic soil amendment treatment effects on total annual yield per plant followed the descending order of N concentration of the amendment. These main effects were consistent across locations, years, and crops. Blood meal and soy pellet plots were the highest yielding treatments, producing 23% and 18% more yield than control plots, respectively ($P=0.03$). Blood

meal plots also yielded 13% higher than 2x cow manure compost plots (Fig. 1). Yields in cow manure compost, chicken manure compost, and 2x cow manure compost treatments were similar to the unfertilized controls.

Treatment effects on crop yield throughout the growing season

Known differences of N release rates between amendments (Guster et al. 2005; Hartz and Johnstone 2006) and the opportunity for farmers to draw early season price premiums on high tunnel crops prompted us to analyze treatment effects on crop yield across sites but separately for each year to determine if treatment effects differed between early season, mid-season, and late season harvest periods. Organic amendments had no effect on yield in 2020. In 2021, treatment effects on yield per plant followed the same trend as our overall analysis (combined site-years), with blood meal and soy pellet plots consistently yielding highest. An interaction between treatment and crop shows us that the effects of soil amendment on crop yields were notably more pronounced in cucumbers than tomatoes ($P=0.02$).

However, a four-way interaction shows us how treatment effects on yield per plant varied by crop, location, and harvest period ($P=0.05$). There was no early season yield advantage observed in tomato plots for any treatment-location combinations. Blood meal was the highest yielding treatment in tomato plants, with a more notable effect late in the season in Bozeman than in Corvallis. In contrast, amendment effects on cucumber yields were more pronounced early in the season compared to late, but these effects were also stronger in Bozeman than in Corvallis.

Cucumbers compared across sites is the best representation of the extent of treatment effects observed in the study (interaction between treatment, crop, and harvest window, $P<0.003$;

Table 4). Early in the second year of the study, all treatments except 2x yielded higher than control plots. All plots were amended in the beginning of the season, while 2x and control plots went unamended prior to planting. By mid-season, blood meal, soy pellets, and cow manure compost plots held a yield advantage, and by the end of the season soy pellets plots was the only treatment outyielding control plots (F-Table, Treatment X Crop X Harvest window $P < 0.003$). This supports the overall analysis that shows blood meal and soy pellets having the greatest advantage over unamended plots (Fig. 1), and in a few instances earlier in the second year, other compost plots may confer a yield advantage over control and 2x cow manure plots.

Organic Soil Amendment and Soil Nitrate

Overall, averaged across all sites, locations, and years, all organic fertilizer treatment plots had higher soil nitrate N levels than control plots (F-table main treatment effects, $P < 0.0001$). When site-years were combined, blood meal plots had over 4 times higher soil N than control plots, over 2 times (2.17x) more than cow manure compost & 2x cow manure compost, and almost 2 times (1.95x) more than chicken manure compost. Soy pellet plots had 70% higher soil N levels than 2x cow manure compost and cow manure compost plots. Chicken manure compost plots had 2x (2.08x) as much soil N as the control plots, and 2x cow manure compost and cow manure compost plots had 87% higher soil N than control plots.

Although different treatments with the exception of control applied the same amount of total N, plots that were amended with low C:N fertilizers exhibited higher levels of soil nitrate than plots amended with high C:N fertilizers. This is consistent with the notion that higher N containing amendments, with higher proportions of soluble N, release N more rapidly than amendments with lower constituent N concentrations. Treatment effects on soil N were

consistent across sites but varied across years and time within the growing season. The interaction between treatment and year was significant ($P=0.001$) and revealed that all compost fertilizer amendments had similar N levels during the first year, but by the second year of the study, N levels in the 2x treatment plots were lower than chicken and cow manure composts plots.

A treatment by time interaction also revealed that soil amendment effects on soil N levels varied throughout the growing season (Fig. 2; $p\text{-value}<0.0006$). All plots had similar soil N levels going into the season, prior to amendment application. Blood meal plots had consistently higher soil N levels than all other treatment plots except soy pellet plots throughout the growing season. Soy pellet, chicken manure compost, cow manure compost, and 2x cow manure compost plots all had similar levels of soil N throughout the season, with soy pellet plots sometimes having higher N (i.e., early June, early July, early August, October). Control plots had the lowest N levels across the growing season.

Discussion

We set out to see if organic fertility amendment C:N was an adequate predictor of crop yield and soil N or if any amendment conferred early season yield advantages. Many predictors of N mineralization in organic fertilizers have been suggested, yet major drivers of this process such as temperature, moisture, and amendment stoichiometry vary so widely from system to system that generalizing soil management strategies may not apply to all production and climatic contexts. In areas where climatic conditions limit growing degree day accumulation and seasonally restrict microbial activity, with soils being frozen for up to 5 months out of the year, optimizing the synchronicity between N availability and crop uptake becomes increasingly

important to maximize productivity in short market windows. In our two locations in Montana, fertilizer effects on both crop yield and soil nitrate were observed in the same order of the amendment N concentration, with plots fertilized with low C:N amendments yielding higher and containing more soil N than crops fertilized with high C:N amendments. In general, organic fertilizer effects on crop yield and soil nitrate were consistent across locations, years, and crops, which suggests that amendment stoichiometry remains a good predictor of soil N and crop performance regardless of environmental conditions. The most notable difference in soil N from year to year is seen in the 2x cow manure compost plots, which was the only treatment other than the control to decrease overall soil N in the second year of the study. The expectation for these plots to mineralize residual N from the year 1 application was not evident in our system, where other studies have shown continual N release into year two after application (Gale et al., 2006; Guster et al., 2005; Hartz et al., 2000). This implies that the residual N was lost from autumn mineralization when soil samples were not being collected, all of the residual N was taken up by plants, or that more time and amendment additions were needed to see the enhanced SON release from additions of mature compost products seen in other studies (e.g., Chalhoub et al. 2013).

Difficulty ripening tomatoes in home garden settings in places like Montana create an early season fervor for these prized fruits, which can draw price premiums early in the season in local markets. By analyzing years separately to parse out trends throughout the growing season we found that tomatoes were not significantly affected by the type of organic soil amendment. In cucumbers, however, early season treatment effects were stronger than late season treatment effects. This could be due to a later onset of yield in tomatoes than in cucumbers.

In fact, it was cucumber crops grown in 2021 that really drove the treatment effects in our combined site-year analysis, as treatment effects in 2020 were not significant. While cucumbers do not draw the same price premiums early in the season like tomatoes do, the difference between blood meal and control plots was almost \$1,000 worth of cucumbers in Bozeman through July, and more than \$1,600 over the course of the growing season. Even the second lowest yielding treatment produced almost \$500 worth (or \$1.11 per square foot) of cucumbers more than the control plots over the course of the growing season. And even though differences in tomato yields were not statistically significant, blood meal plots produced over \$1,000 worth of tomatoes more than control plots in Bozeman throughout the growing season in 2021. These estimates were based on extrapolating our yield per plant value to reflect 450 ft² of production, which represented the amount of cultivation at our Bozeman site. This is a conservative estimate as most market farms cultivate more square footage than that. Values were estimated using pricing from MSU's campus farm: early season tomatoes were \$4.50 per half pint (~8 ounces), mid-late season tomatoes were \$4 per half pint, and cucumbers were \$2 per cucumber. Even with the cost of applying 450 ft² with the most expensive amendment (\$31.50), the lowest yielding treatments bring in more revenue than control plots.

Blood meal and soy pellet plots exhibited dramatic spikes in soil N levels in the first 30 days after incorporation while compost fertilizers showed a more consistent release of N throughout the season, which is consistent with other studies showing the fast release of N from high N-containing organic amendments (Figure 2; Hartz 2006). In contrast, however, we see late season spikes of soil N in blood meal and soy pellet plots, as well as average values being higher than the N supplied through amendment, which could suggest that excess N fueled a resource

pulse of microbial activity that led to N- release through organic matter mineralization (Bonanomi et al. 2017; Schmidt et al. 2018; Olson-Rutz, personal communication). It is possible that SOM, which was inherently high at our study sites (4-5%), was mineralized to provide this late season N spike. Alternatively, high late season N in these plots could be explained by an accumulation of N because crop yield is slowing and plants are not using as much N as they are early in the season.

The analysis suggests that composted fertilizers with high C:N do not have significant effects on crop yield compared to unamended soil, which is consistent with other research conducted in soils not limited by P or K (Marshall et al. 2016). This lack of differences between control plots and those amended with compost can partially be explained by looking at our nitrate data, which suggest that compost plots only mineralized a fraction of the N they contain, and is consistent with what we know about the slow release rates of stabilized composted products compared to the rapid release of specialty products such as blood meal (Gale et al., 2006; Guster, 2005; Hartz et al., 2000; Hartz & Johnstone, 2006; Tyson & Cabrera, 1993).

Yet these plots display higher soil N levels and yielded 10-17% more for cucumbers, and 1-5% more for tomatoes, which equates to substantial monetary gains when extrapolating yield per plant differences to a production scale with hundreds of plants in the ground. Residual effects of long-term additions of high C:N organic matter also increase the organic soil N pool (Guster 2005), which might explain the seemingly small magnitude of difference between compost fertilizer plots and control plots, as each location in this study has a history of over 10 years of consistent organic inputs. The low intensity of our crop rotations (1 crop/year) compared to rotations typical in commercial high tunnel vegetable production (2-3 crops/year) may also

explain the small magnitude of difference between control and compost treatment plots. We suspect our lack of cropping intensity may leave more residual N in the soil than more intensely cropped systems. In our study, skipping a year or two of soil amending did not severely restrict crop yield (control plots), yet our second lowest yielding plots (2x cow manure compost) still provided meaningful revenue differences.

Conclusion

Amendment stoichiometry is an important driver of nutrient mineralization and can be useful to consider when devising fertility management strategies as a farmer. Climatic constraints on growing conditions pose unique challenges to soil fertility management, such as aligning the window of nutrient mineralization with crop needs. In an effort to determine whether the general relationship between amendment stoichiometry and N mineralization holds true in our northern climate with seasonally restricted microbially activity, we found that the rapid N release of high N organic fertilizers (i.e., blood meal, soy pellets) had a greater impact on yield formation in heavy feeding high tunnel crops than compost fertilizers with slower N release rates. Even high C:N fertilizers increased productivity in a financially meaningful way over unamended soils. Because soil nitrate concentration and crop yield are both measures that represent a myriad of complex biological processes, we cannot speak to the mechanisms of any treatment effects observed. It is important to emphasize, however, that while amendments with a low C:N will likely increase yields more consistently in the short-term, we also advise the routine addition of compost-based fertilizers with higher C:N to the soil for the purpose of long-term enrichment of the organic soil nutrient pool, based on our control plots with high inherent SOM maintaining similar yields to compost amended plots and other studies that showing

increases in organic nutrient pools with long-term compost additions (Flavel et al., 2006; Gale et al., 2006; Hartz et al., 2000).

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Table 1. Soil, growing season, and high tunnel characteristics for both study sites. Samples were taken in the spring of 2020 prior to amending soil.

Site characteristics								
<u>Growing</u>								
<u>Degree Days</u>								
Location	N	P	K	OM	pH	2020	2021	HT dimensions ^z
	(Nitrate)	(Olsen)						
	(ppm)	(ppm)	(ppm)	(%)				
Bozeman	41	144	620	5.1	7.3	1800	2062	3 tunnels, 30ft. X 50ft.
Corvallis	39	160	461	3.2	8.1	1888	2096	1 tunnel, 30ft. X 60ft.

^zBozeman had three high tunnels, Corvallis had one high tunnel

Table 2. N-P-K concentrations of organic soil fertility treatments used in study

Treatment	N-P-K	C:N	Application rate (g N · m ⁻²)
Blood meal	13-0-0	3	14
Soy Pellets	7-0.4-1.66	6	14
Chicken manure compost	3-0.9-1.66	13	14
Cow manure compost	1.6-0.3-0.8	25	14
2x cow manure compost	1.6-0.3-0.8	25	28

Table 3. F-Table of our combined site year analysis of our split-split plot design. The response variable is yield per plant (kg).

Error: Block (random effects)					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Location	1	4.172	4.172	27.58	0.00629 **
Residuals	4	0.605	0.151		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Error: Block:Tx (whole plot effects)					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Tx	5	0.5641	0.11282	3.06	0.0328 *
Tx:Location	5	0.0793	0.01587	0.43	0.8221
Residuals	20	0.7375	0.03687		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Error: Block:Tx:Crop (split plot effects)					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Crop	1	17.220	17.220	1528.022	< 2e-16 ***
Tx:Crop	5	0.109	0.022	1.930	0.12655
Crop:Location	1	0.088	0.088	7.834	0.00995 **
Tx:Crop:Location	5	0.093	0.019	1.659	0.18284
Residuals	24	0.270	0.011		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Error: Within (split-split plot effects)					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	1	1.0775	1.0775	1.500	4.55e-11 ***
Tx:Year	5	0.0975	0.0195	1.294	0.282
Crop:Year	1	0.4903	0.4903	32.534	7.08e-07 ***
Location:Year	1	0.9577	0.9577	63.554	2.43e-10 ***
Tx:Crop:Year	5	0.0746	0.0149	0.990	0.434
Tx:Location:Year	5	0.0887	0.0177	1.177	0.335
Crop:Location:Year	1	0.0002	0.0002	0.015	0.903
Tx:Crop:Location:Year	5	0.0451	0.0090	0.598	0.701
Residuals	48	0.7233	0.0151		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Figure 1. Effect of organic soil amendment on mean total annual yield per plant across crops, locations, and years. Means were separated using Fisher's LSD test with pooled SE of the treatment difference = 0.03687; $P < 0.05$. BM, blood meal; SP, soy pellets; CWMC, cow manure compost; 2xCWMC, 2x rate of cow manure compost; CKM, chicken manure compost; CNTL, control.

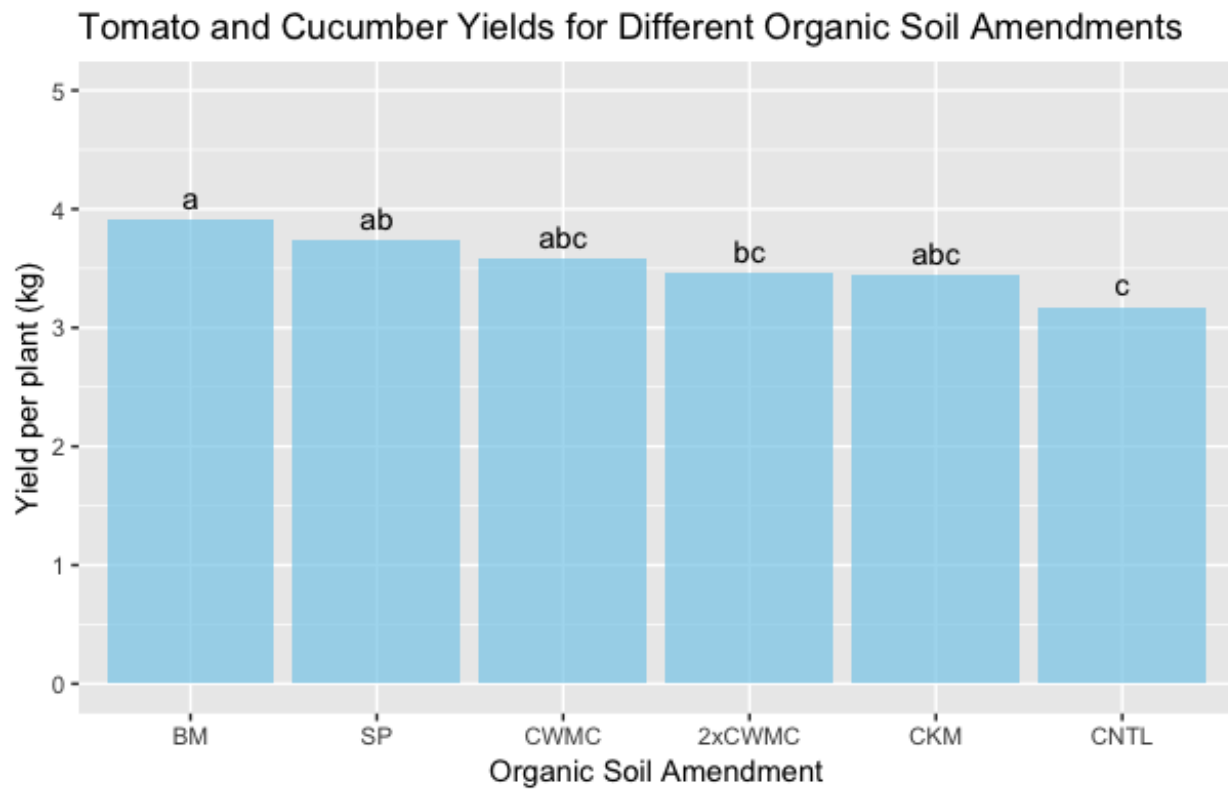
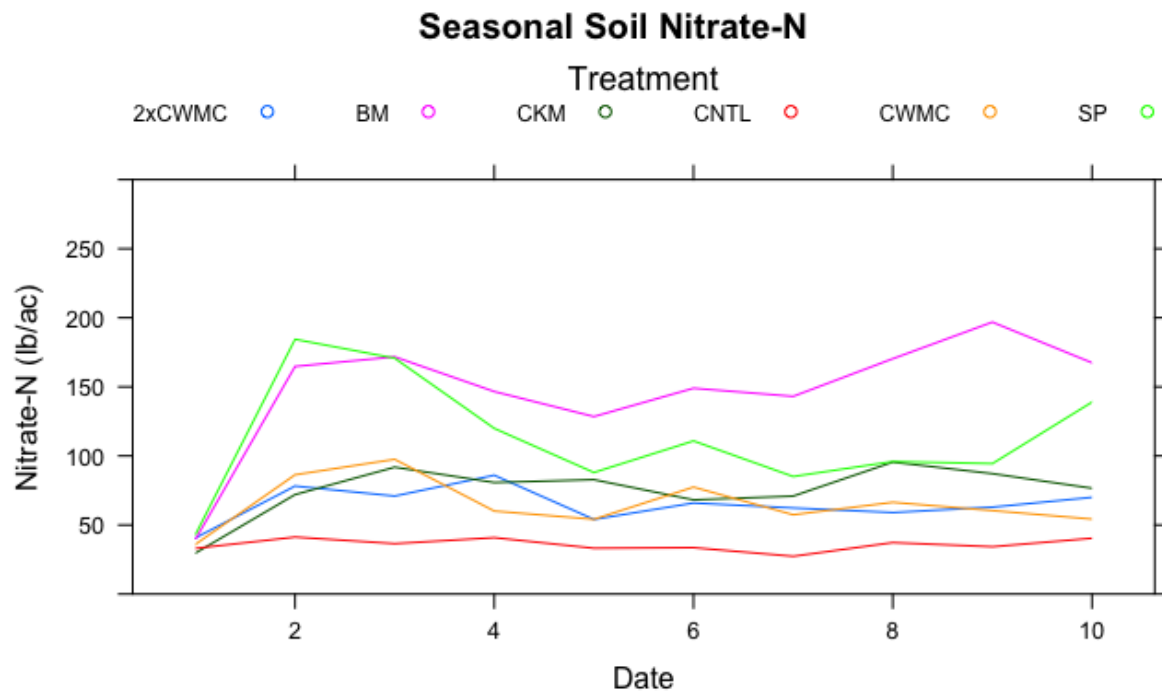


Table 4. Influence of organic soil amendment on cucumber yield (kg/plant) across both locations in 2021. F-Table, Interaction of Treatment X Crop X Harvest window $P < 0.003$.

Cucumber fruit wt (kg) per plant			
Treatment	<u>Harvest window</u>		
	Early season	Mid season	Late season
Blood meal	2.29*	1.51*	0.92
Soy pellets	1.97*	1.35*	1.01*
Cow manure compost	1.87*	1.37*	0.99
Chicken manure compost	1.75*	1.27	0.79
2x cow manure compost	1.61	1.11	0.81
Control	1.43	1.22	0.80

* Indicates significant difference from the lowest yielding treatment for each harvest period (lowest yield indicated **in bold**) derived from post-hoc means separation test, Fisher's LSD using pooled SE of differences within treatment x crop x month = 0.028.

Figure 2. Effect of organic soil amendment on mean soil nitrate-N throughout the growing season averaged across crops, locations, and years. (F-table, Treatment X Time interaction, $P < 0.0006$; Post-hoc test LSD value ($\log(\text{nitrate})$) = 0.40). BM, blood meal; SP, soy pellets; CWMC, cow manure compost; 2xCWMC, 2x rate of cow manure compost; CKM, chicken manure compost; CNTL, control. X-axis dates: 1, late May; 2, early June; 3, late June; . . . 9, late September; 10, early October.



CHAPTER FOUR

ACTIVE LEARNING INTERVENTION IMPROVES QUANTITATIVE REASONING SKILLS IN UPPER-LEVEL CROPPING SYSTEMS COURSE

Contribution of Author and Co-Authors

Manuscript in Chapter Four

Author: Charles Watt

Contributions: I conceived the study, collected and analyzed data, and wrote and revised the manuscript.

Co-Author: Mac Burgess

Contributions: Helped conceive the study, mentored first author with implementing the study and the study intervention, and assisted with editing and revising of manuscript.

Co-Author: Carrie Myers

Contributions: Mentored first author with study design and data collection and analysis. Assisted with editing and revising of manuscript.

Manuscript Information

Charles Watt, Mac Burgess, and Carrie Myers

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Abstract

Graduates from agricultural degree programs are expected to have competencies and skills that enable them to be effective leaders in food-systems. Specifically, instructors and industry professionals alike expect emerging graduates to have the ability to quantitatively reason with soil related data to inform decision making. This Solomon Four Group classroom research study addressed student deficiencies in upper-level Crop Science and Sustainable Food & Bioenergy Systems students ability to quantitatively evaluate a farmer's claim of increasing soil organic matter (SOM) levels and apply it to a specific cropping system context by testing whether an active learning intervention led to improvement in student performance measured by an assessment question. We found that when an active learning intervention was paired with didactic delivery of content, students improved in their critical thinking, quantitative reasoning, and ability to communicate these results in an applied context. By breaking the assessment into domains that were relevant to each of these three outcomes, we found that the active learning intervention was more helpful in developing proficiency in quantitative reasoning, and that didactic instruction may be adequate in preparing students in logical reasoning and communication of applied concepts. Our findings suggest that simple active learning activities such as problem-sets and peer to peer discussion can have valuable impacts on students capacity to reason with complex issues relevant to agriculture.

Active Learning Intervention Improves Quantitative Reasoning Skills in Upper-Level Cropping Systems Course

Improving agricultural systems requires a diverse skillset and a breadth of knowledge to effectively engage in the complexity of our food system. Skill development emphasizing communication, critical thinking, and teamwork are necessary if we want students to succeed in this industry upon graduation. The increasingly multidisciplinary nature and inherent complexity of our food systems, as well as our contemporary understanding of learning theory, requires our educational institutions to adapt and adopt an approach that reflects the dynamic nature of both food-systems and study body needs (Hilimire, 2016; Jordan et al., 2014).

Agricultural graduates must not only have competent technical skills that range across physical and life sciences, but these skills must be applied in sociocultural contexts that require interpersonal skills and communication. Because everyone must eat, agriculture directly connects concepts and fields that may not be considered together in other disciplines (Jacobson and Wilensky, 2006). Additionally, it is unclear what constitutes good agricultural practices and how we might achieve sustainability goals (Behm, 2011; Bonnett, 1999). This creates a problem space that is unique to students studying agriculture. This nexus of complex physical, biological, and social processes poses challenges to educators tasked with preparing students for work in such a transdisciplinary setting, but common approaches and themes have been identified by educators (Jabbour & Pellissier, 2019).

This research arose from anecdotal evidence that suggested upper division students in the College of Agriculture at Montana State University were not sufficiently meeting program-wide learning outcomes in assessment measures related to critical thinking, quantitative reasoning, and

communication/public discourse. Specifically, there was concern over the ability of students to synthesize and apply academic concepts to real-world examples, which are important competencies for entry-level food industry work. While the College of Agriculture has many pedagogical strengths, including, but not limited to, experiential learning opportunities, integrating research in undergraduate settings, and individual teachers adopting active learning methods, didactic modes of content delivery still dominate classroom settings at MSU, and in most public post-secondary institutions at large. Yet, there is research showing that the dominant lecture approach to content delivery is not the most effective way to engage students (Slavich & Zimbardo, 2012), and that utilizing active learning principles can enhance learning (Ismail & Groccia, 2018; McKeachie & Svinicki, 2014), especially in STEM settings (Burrows & Slater, 2015; Fairweather, 2008; Freeman et al., 2014; Kelley & Knowles, 2016; Labovet et al., 2009).

The basis for enhancing active engagement with content material is constructivist learning theory which suggests that students learn by making meaning of their experiences (Lord 1997; Piaget 1926; Vygotsky, 1978). Principles such as active learning and student-centered learning facilitate deeper learning in students versus lecture styles that focus on mastery of content (Ishmail & Groccia, 2018). Instructional methods emphasizing systems thinking, multi-, inter-, and transdisciplinary perspectives, experiential learning, place-based learning, integration of teaching and research, and collective community partnerships and action get at the heart of constructivist learning theory by encouraging students to make meaning from direct experiences and using them to contextualize and process new ideas and information (Andrée et al., 2016; Ahmed et al., 2017; Slavich and Zimbardo 2012; Valley et al., 2018). Learning that is embedded in a social context further enhances students' meaning-making ability (Jarvis, 2018; Kraus, 2012).

and is a necessary approach given the highly interpersonal nature of food system work (Jachowski et al., 2022). While some of these instructional methods may be limited in their capacity for classroom application, teachers still have endless ways to bring active learning into classroom settings (e.g., collaborative learning, problem-based learning, reflection). By having students build dynamic relationships between students, teachers, themselves, and content, and by engaging students in higher-order cognitive strategies, providing multiple contexts and settings to process information while using peer interaction, and having students reflect on their experiences, teachers can engage students more deeply and in ways that will maximize their potential for intellectual growth (Ismail & Groccia, 2018; Miller, 2011; Quinlan, 2016; Smith et al., 2009; Slavich & Zimbardo, 2012). they can engage more deeply and retain information more readily (Quinlan, 2016).

(<Insert Figure 1 here>)

Issues facing agriculture today are so multifaceted, nuanced, and applied, that the capacity for students to critically evaluate claims about, for instance, the rate at which soil improves (an inherently complex and poorly understood process) requires effective critical thinking, quantitative reasoning, and communication skills. The purpose of this research was to determine the effects of an active learning intervention on students' ability to evaluate such claims in a 400-level cropping systems course at Montana State University (MSU). Specifically, we wanted to know 1) whether an active learning intervention that utilized peer-peer interaction, reflection, and problem-sets increased student outcomes on an assessment measure, and 2) whether administering a pretest would elicit effects on the behavior of students, the results of the assessment measure, or the effectiveness of our intervention. Our research is novel due to the

unique challenges found in agricultural education, where students are expected to have more nuanced and applied understandings of academic concepts. In our example, we were not only interested in the student's capacity to solve a word problem quantitatively, but we were interested in whether they could convey whether the answer they found is feasible in a dryland cropping system. We utilized a Solomon Four-Group experimental design to strengthen our inference power of the effectiveness of the intervention by accounting for pre-testing effects of the assessment measure. Our results suggest that utilizing active learning principles is more effective in preparing students to deal with complex agricultural concepts than traditional lecture approaches. This has important curricular and pedagogical implications.

Materials and Methods

Study Participants and Study Design

This study was born from an assessment event that was aimed to measure program-wide learning outcomes in several degree programs at the College of Agriculture at MSU. Upon finding results (which comprise year 2019 of this study) that indicated low achievement in critical thinking, problem solving, and communication and public discourse skills, we developed an experiment that tested the effects of an active learning intervention on students' capacity to achieve these outcomes. We felt that active learning principles encouraged a depth of engagement that was necessary to grasp the multifaceted and interconnected nature of certain food system issues.

We used the Solomon four-group experimental design because of the increased inference power it provides to classroom research by controlling potential confounding variables that typically affect internal validity and to parse out pretesting effects that often go unaccounted for

in simpler experimental and quasi-experimental designs (such as the more popular pretest-posttest design or posttest only control design; Solomon, 1949; Campbell and Stanley, 1963). The unique design of this study bolsters our capacity to assume cause and effect from our active learning intervention and allows us to generalize our findings beyond the scope of our own study. The study occurred over four academic years, from 2019 to 2022, with each year's cohort of students comprising the different experimental groups, which were defined based on whether students participated in an active learning intervention and whether they took a pre-test. Since the research design was inspired by an existing assessment(2019), assignment of the first year's treatment group was not random. Prior to 2020, the remaining three years were randomly assigned to treatment and pretest combinations, however, the effects of the COVID 19 pandemic and resulting sudden transition to online learning prompted us to change which groups received interventions (Table 1). It's worth mentioning that the 2020 treatment group was the most affected by COVID, as MSU's campus transitioned to online learning mid-way through the semester. This meant that the posttest in 2020 was administered on an exam that was done at-home. Student cohorts in 2021 and 2022 both received in-person instruction, yet still displayed hesitation when it came to group work due to social distancing and mask mandates.

(<Insert Table 1 here>)

The study was comprised of 96 students enrolled in Agricultural Science (AGSC) 428 / Land Resources and Environmental Science (LRES) 529 *Cropping Systems and Sustainable Agriculture* in the College of Agriculture at MSU in Bozeman, Montana. Crop science and Sustainable Food and Bioenergy Systems (SFBS) majors are required to take the course while

students from other majors (Horticulture, Agriculture Education) and graduate students in the College of Agriculture enroll in this course as an elective option.

Assessment Measure Instrument

Our assessment measure was inspired by the need to assess program wide learning outcomes in AGSC 428 for both Crop Science and SFBS majors. This course occurs at the end of a required three-course sequence, with each course requiring student achievement of specific program wide learning outcomes, leading to achievement of all outcomes by the end of the course sequence. Prior to 2019, there were no assessment checkpoints in the course sequence to gauge student progression in program-wide learning outcomes for both majors, whose intended outcomes are very similar to each other (Table 2).

(<Insert Table 2 Here>)

The outcomes intended to be measured in AGSC 428, which were designated by the program assessment committees, can be summarized as critical thinking, problem solving skills, and the ability to demonstrate agency or lead the public discourse on agriculture. If students achieve the outcomes outlined in the program assessment plan in prior courses in the sequence, upper-level students should be able to synthesize information necessary to answer questions that demonstrate mastery of multiple learning outcomes. To measure these specific outcomes, we provided a problem in which students were to evaluate and respond to a farmer's claim of soil organic matter (SOM) increases (Figure 2). Many instructors in the field of agriculture have identified that holistic thinking and interpreting soil data for management decisions is a top priority for undergraduate students (Jabbour & Pellissier, 2019).

Our assessment measure comprised of three domains that were associated with our targeted program-wide learning outcomes; the ability to convert a word problem to an algebraic equation (critical thinking), the ability to execute a calculation correctly (quantitative reasoning), and the ability to logically apply their answer to a real-world context (communication). To answer all three components successfully required synthesis and application of knowledge gained throughout the three-course sequence. The assessment measure was assessed by the same researcher each year and was scored with a binary result for each question domain (0/1, failure/success). We also recorded the total score for each student, which manifested as a score from 0-3. Preliminary results from our assessment of a SOM claim indicated that many students could not convert a word problem into a simple algebraic expression, could not correctly execute a simple algebraic expression, could not recognize reasonable amounts of dryland biomass production, and had a poor understanding of major soil health concepts such as nutrient cycling and carbon storage.

(<Insert Figure 2 Here>)

Considered separately, the individual domains of the assessment problem require lower-order cognitive skills, yet when presented in the context of a real-world example, the critical thinking, quantitative reasoning, and ability to draw inference needed to adequately address the problem demands high order thinking (Bloom et al., 1956; Krathwohl & Anderson 2001). Since students were not sufficiently demonstrating the high order thinking required to evaluate a soil health claim, we designed this study to determine whether implementing an active learning activity aimed to address these concepts would improve student outcomes.

Active Learning Intervention

The active learning intervention designed to teach this concept was derived from CAT 21 from Angelo and Cross's Classroom Assessment Technique's Handbook (1993). It comprised a problem set of increasing difficulty, done in a peer setting (Appendix A). The specific intervention is designed to address quantitative problem-solving skills. The activity includes problem-based learning, problem sets, and peer-peer interaction, and meta-cognition/reflection. The intervention followed a lecture that covered concepts that were relevant to calculation on our assessment instrument. Control groups received the same lecture, however the calculation was covered didactically, while experimental groups were encouraged to engage actively with the calculation. We hypothesize, based on research in support of active learning, that groups who received the intervention will be better equipped to successfully complete our assessment measure. Specifically, we thought having students note where they became stuck and instructing them to clarify why they were stuck, or what information was need for them to proceed, would develop more proficiency in their ability to identify what information is needed and how to apply or organize it in order to answer problems of this caliber. Conducting the problem-set in a peer setting and including metacognitive engagement of their problem-solving process is intended to enhance their ability to apply these practices to other problems requiring quantitative problem-solving and critical thinking.

Analysis

We analyzed data using chi-square analysis because our experiment had binary categorical outcomes (0,1; or failure/success) and more than two levels in both the explanatory and response variables. This approach was selected, as opposed to linear regression or mixed

modelling approaches, because we lacked descriptive data that would lend more value to these approaches (Seltman, 2018).

Solomon four-group study designs enable the comparison of specific group and treatment combinations that are intended to provide checks on both internal and external validity. It allows us to parse out intervention effects from pre-testing effects and the compounding effects of extraneous variables, such as history and maturation of the student, which bolster our ability to generalize our research to other classroom settings. The first analysis included a comparison of two sets of treatment groups; the results of 2019 posttest v. 2022 posttest were compared to 2020 posttest v. 2021 posttest (Table 1). This enabled us to determine whether the pretest had any effects on the results of the assessment measure. The second analysis included a comparison of 2020 pretest to 2019 posttest, which enabled us to determine if there were any external factors affecting results and allowed us to infer causality. The third analysis included a comparison of 2021 posttest to 2022 posttest, which enabled us to determine whether the pretest had any effects on the treatment intervention. The fourth analysis included a comparison of 2020 posttest to 2019 posttest, which enabled us to determine if the pretest had any effects on the assessment results independently of the intervention effects.

Since assessment measure scores were broken into three separate domains (four including the summed total of the three components) and we needed to make five different comparisons that supported our ability to draw inference on pretest and intervention effects according to our Solomon-four group design, we wound up making 20 distinct post hoc chi-square comparisons. Making this many post hoc comparisons increases our chances for Type I errors to occur, yet using Bonferroni's method to correct of Type I error, which would give us corrected alpha of

0.0025, increases our chances for Type II errors to occur. In an effort to maximize the inference power that utilizing Solomon Four Groups designs confers, we chose to leave our alpha value at 0.05 and let the reader make judgements on the confidence in our suggestions. We acknowledge the risk and limitations that come with our decision.

Results

Descriptive Statistics

The total sample included 96 students. The sample included 43 students that received a pretest, 17 (40%) in the active learning intervention group and 26 (60%) in the control group. While there were 54 students who did not receive a pretest, 25 (46%) in the active learning intervention group and 28 (54%) in the control group. Table 3 displays the pretest assessment scores for each question domain of the assessment measure, as well as the summed total score, for the two groups that received a pretest. Table 4 displays the post-test assessment scores for all four experimental groups.

(<Insert Table 3 here>)

(<Insert Table 4 here>)

Pretesting Effects on Assessment Results

In the comparison between groups that did not receive a pretest, the group that received an active learning intervention (2022) scored significantly higher on the posttest than the control group (2019) ($X^2 = 20.68$, $p = 0.0001$; Table 5A). Out of the 25 students in 2022, 16 (64%) of students received full credit (3/3 points), 4 (16%) received 2 points, 4 (16%) received 1 point, and 1 (4%) student received 0 points. In contrast, out of the 28 students in 2019, 7 (25%)

students received full credit, 4 (14%) received 2 points, 8 (29%) received 1 point, and 9 (32%) received 0 points.

In the comparison between groups that did receive a pretest, the group that received an active learning intervention (2021) scored significantly higher on the posttest than the control group (2020) ($X^2 = 11.9$, $p = 0.008$; Table 5B). Out of the 26 students in 2021, 11 (65%) of students received full credit, 3 (18%) received 2 points, 1 (6%) received 1 point, and 2 (12%) student received 0 points. In contrast, out of the 17 students in 2020, 7 (27%) students received full credit, 6 (23%) received 2 points, 9 (35%) received 1 point, and 4 (15%) received 0 points.

Since the result of both comparison groups are the same, it can be said the pretest did not have strong effect in this study. These trends are consistent between the word and calculation domains of the question. However, in the 2019/2022 comparison, the p-value for the logic domain is slightly higher ($p = .07$) than in the 2020/2021 logic domain ($p = 0.02$). This is a slight difference but significant and indicates that the pretest may have had some effect on the logic portion of the exam

(<Insert Table 5 A & B here>)

External Influences on Assessment Results

(2019 Post v 2020 Pre)

The significant difference in total scores on the assessment measure between the 2020 pretest and the 2019 posttest indicates that there may be external factors influencing the assessment results ($X^2 = 19.54$, $p = 0.002$; Table 6).

In contrast to the 2019 posttest scores, out of the 17 students in 2020 who took the pretest, 3 (12%) students received full credit, 5 (19%) received 2 points, 0 received 1 point, and 18 (69%) received 0 points.

The test statistic for the comparison of total scores ($X^2=19.54$) indicates that the 2019 posttest group performed better on the assessment measure despite not having received an active learning intervention. However, we must keep in mind that the 2019 posttest group still received didactic instruction on concepts related to the assessment measure, while the 2020 pretest scores represent an assessment that was taken prior to any classroom exposure to the specific problem that semester.

In examining the individual assessment domains, the logic domain is the only area that students performed better on the 2019 posttest, while the word and calculation domains were not different between groups. This lack of difference in the word and calculation domain indicate that our intervention was the cause of increased student achievement in these two domains.

Further, the magnitude of difference of the logic domain between the two groups ($X^2=9.17$, $p=0.002$) was not as drastic as the total summed scores, indicating the potential for other external factors to contribute to the apparent difference.

(<Insert Table 6 here>)

Pretesting by treatment effects

(2021 Post v. 2022 Post)

There was no difference in total scores between the posttest scores of the two groups that received the active learning intervention, which suggests that that the pretest did not have any influence on the treatment effects (Table 7).

However, there is a difference between the posttest scores on the calculation and logic components of the assessment measure (Table 7). While this indicates that the pretest has some sort of effect on the posttest results, and would suggest an experimental flaw, one group does better on the calculation domain (2022) while the other group (2021) does better on the logic domain. This may indicate that those who receive a pretest are primed to think about the logical implication of such a problem, while those who were not exposed early may have not ascribed as much importance to their ability to draw inference

(<Insert Table 7 here>)

Pretesting effects on behavior

(2019 Post v. 2020 Post)

There were no observed differences between the posttest assessment scores of the two groups that did not receive an active learning intervention (Table 8). Therefore, the pretest had no effect on the behavior of the students independent from the treatment intervention. This gives us confidence that our treatment was the main factor contributing to student achievement of our assessment measure.

(<Insert Table 8 here>)

Discussion

Evidence from this research suggests that an active learning intervention improved student outcomes in critical thinking, problem-solving, and communication. When we only consider the summed total score of individuals, there is a strong case to be made that the active learning intervention in our study improved student's capacity to solve our assessment measure.

In dividing our assessment instrument components into separate domains that correspond to three different learning outcomes, we can unpack how our intervention may have affected certain outcomes more strongly than others. Since our experimental design worked to limit threats to internal and external validity, our desire to maximize inference power prompted use of an uncorrected alpha value of 0.05.

Our results indicate that there was no pretesting effect on the assessment results. Groups that did not take a pretest displayed a higher magnitude of improvement from the intervention than groups that did take a pretest, but the groups that received an active learning intervention also scored significantly better than groups that didn't. This clearly demonstrates the positive impact that active learning interventions can have on student's quantitative reasoning, critical thinking and communication skills.

The similarity between 2020 pretest scores and 2019 posttest scores for the word and calculation domains suggest that any improvements seen in groups that received the intervention can be attributed the intervention itself (Table 6). This is true most specifically for word and calculation domains. However, we cannot imply causality from the intervention on logical domains and overall scores because improvements were observed in the 2019 posttest despite not receiving an intervention. This might suggest that didactic instructional methods may be adequate in preparing students for logical application, while active learning is necessary for improving word problem solving and calculation skills. This is unsurprising, as other modules in this course convey the importance of knowing reasonable quantities of biomass in dryland production (the context for the logical domain of our assessment instrument) and students are encouraged to become familiar with reasonable production quantities across many cropping

systems contexts throughout their entire degree program. In order to make this type of active learning intervention more effective in improving logical application skills in students, we suggest providing problem sets that utilize quantitative reasoning in a wider range of applied contexts. We focused specifically on soil organic matter calculations but this activity could be applied in a multitude of other cropping systems contexts (e.g., fertilizer application rates to optimize yield and minimize leaching, water-use efficiency of cropping rotations, etc.)

The pretest had no effect on the behavior of students independent of the intervention and only minimally affected the active learning intervention. Any effect the pretest had on the intervention was limited to the calculation and logic domain. Students were more successful in their calculation if they did not take a pretest, which goes counter to the usual way pretesting positively affects student outcomes (Willson & Putnam, 1982). Firsthand experience and anecdotal evidence from professors in the College of Agriculture at MSU suggest that many students lack confidence in the quantitative analytical skills. It's possible that priming students with an expectation of a math-based assessment could cause them to over-think.

These findings suggest the value of using active learning strategies to engage undergraduate students in complex, multidisciplinary, context-driven problem-solving. Further, it suggests that active learning is an effective complement to didactic modes of delivery, and that its use can be selectively applied to engage students with concepts that are relevant to more advanced learning outcomes. Using formative outcome assessment or consulting literature (e.g., Jabbour and Pellissier, 2019) to identify challenging concepts for students could help instructors target optimal concepts to employ active learning for. Research shows that interrupting didactic delivery of content with Class activities every 15-minute is an effective way to optimize student

attention span (Stuart & Rutherford, 1978; Wilson & Korn, 2007). Lastly, we suggest that more research is needed to identify how teachers can enhance the capacity for their students to learn concepts and build skills that translate to effective decision making in the uniquely interdisciplinary and complex web of applied food-system studies.

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Table 1.

Treatment and pretest combinations in our four-year classroom study. 2021 saw a reduced enrollment in course due to COVID 19 pandemic related changes to classroom enrollment and logistics.

	Treatment group			
	2019	2020	2021	2022
Pre-test	-	X	X	-
Active Learning Intervention	-	-	X	X
Post-test	X	X	X	X
Sample size	28	26	17	25

Table 2.

Program wide learning outcomes for Sustainable Food & Bioenergy Systems and Crop Science majors in the CoA at MSU. Bolded outcomes were assessed in a 400-level course (AGSC 428) at the end of a required 3-course sequence.

<i>Sustainable Crop Production</i>	<i>Crop Science</i>
Systems Thinking	Critical Thinking
Problem Solving Skills	Address Production Problems
Practical Skill - Able to Grow food	Design Effective Cropping Systems
Effective Communicators	Effective Communicators
Capacity to make choices and advocate a position	Lead the Public Discourse on Ag
Have a Body of Knowledge Related to Sustainability	Financially Assess Cropping Practices

Table 3.

Contingency Table of Pre test scores. The 2020 group did not receive the active learning intervention while the 2021 did.

Question	Score	Group	
		2020	2021
Word	0	21	13
		81%	76%
	1	5	4
		19%	24%
	SD	11.31	6.36
Calculation	0	18	10
		69%	59%
	1	8	7
		31%	41%
	SD	7.07	2.12
Logic	0	20	9
		77%	53%
	1	6	8
		23%	47%
	SD	9.90	0.71
Total	0	18	7
		69%	41%
	1	0	3
		0%	18%
	2	5	5
		19%	29%
	3	3	2
		12%	12%
	SD	7.94	2.22

SD= standard deviation

Table 4.*Contingency Table of Post test scores.*

Question	Score	Group			
		2019	2020	2021	2022
Word	0	18	16	4	6
		64%	62%	24%	24%
	1	10	10	13	19
		36%	38%	76%	76%
	SD	5.66	4.24	6.36	9.19
Calculation	0	16	11	5	2
		57%	42%	29%	8%
	1	12	15	12	23
		43%	58%	71%	92%
	SD	2.83	2.83	4.95	14.85
Logic	0	13	9	2	7
		46%	35%	12%	28%
	1	15	17	15	18
		54%	65%	88%	72%
	SD	1.41	5.66	9.19	7.78
Total	0	9	4	2	1
		32%	15%	12%	4%
	1	8	9	1	4
		29%	35%	6%	16%
	2	4	6	3	4
		14%	23%	18%	16%
	3	7	7	11	16
		25%	27%	65%	64%
	SD	4.57	2.08	6.65	2.16

SD= standard deviation

Table 5.

Chi-square analysis that enabled us to determine whether the pretest had any effects on the results of the assessment measure.

A)

Comparison	Question domain	χ^2	p-value
2019 Post v. 2022 Post	Word problem set-up	16.1	<0.0001
	Calculation	22.33	<0.00001
	Logical application	3.37	0.07
	Total	20.68	0.0001

B)

2020 Post v. 2021Post	Word problem set-up	9.9	0.002
	Calculation	3.87	0.05
	Logical application	5.68	0.02
	Total	11.9	0.008

Table 6.

Chi-square analysis that enabled us to determine whether there were any external factors affecting results and allowed us to infer causality.

Comparison	Question domain	χ^2	p-value
2020 Pre v. 2019 Post	Word problem set-up	3	0.08
	Calculation	1.58	0.21
	Logical application	9.17	0.0025
	Total	19.54	0.0002

Table 7.

Chi-square analysis that enabled us to determine whether the pretest had any effects on the treatment intervention.

Comparison	Question domain	χ^2	p-value
2021 Post v. 2022 Post	Word problem set-up	2.56	0.11
	Calculation	9.76	0.002
	Logical application	4.07	0.04
	Total	5.06	0.17

Table 8.

Chi-square analysis that enabled us to determine whether the pretest had any effects on the assessment results independently of the intervention effects.

Comparison	Question domain	χ^2	p-value
2019 Post v. 2020 Post	Word problem set-up	0.22	0.64
	Calculation	2.31	0.13
	Logical application	1.5	0.22
	Total	3.9	0.27

Figure 1.

Conceptual model suggesting the value of utilizing active learning principles, compared to didactic methods, for instructional delivery of inherently complex food-system concepts.

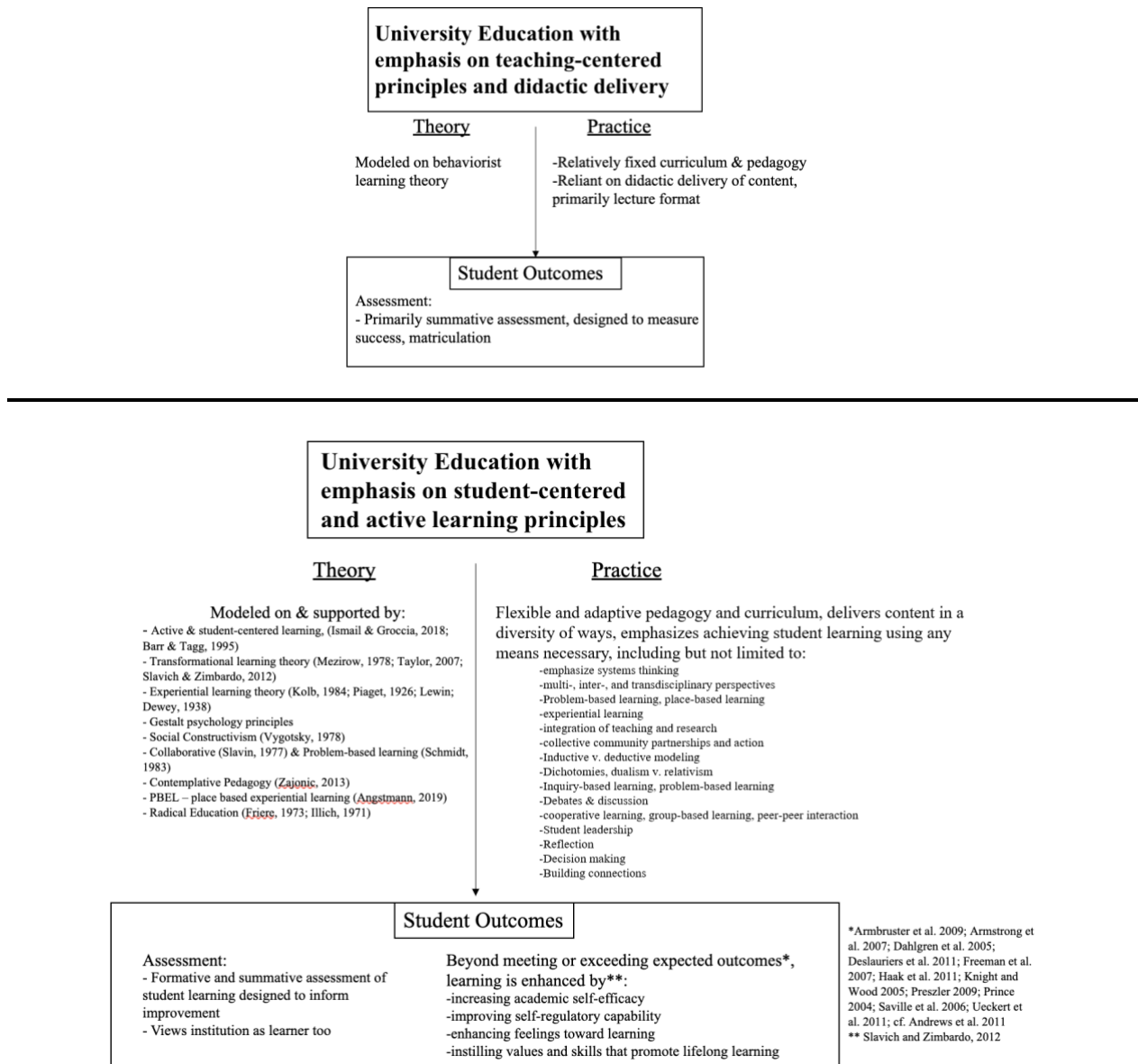


Figure 2.

The instrument of assessment used in this study.

The question:**A.**

A farmer claims to have increased their soil organic matter (SOM) by 3% over 10 years. Focus on the top 6" of the soil, with an acre furrow slice of soil weighing 2,000,000 lbs. Approximately how much cover crop biomass would need to decompose per year in order for this change to occur, assuming a 30% conversion rate from residue biomass to SOM?

To answer this question, the student needs to:

- Convert a word problem into a simple algebraic expression
- Calculate algebraic expression without error
- Recognize reasonable quantities of agricultural production

Step 1. How much organic matter is that per acre?

$$2,000,000 \text{ lbs soil} \times \frac{3 \text{ parts OM}}{100 \text{ parts soil}} = 60,000 \text{ lbs of Organic Matter}$$

Step 2. How much plant biomass would need to be returned to the soil for that increase in organic matter to occur?

$$60,000 \text{ lb Organic matter} \times \frac{1 \text{ parts Cover Crop Biomass}}{0.3 \text{ parts Organic Matter}} = 200,000 \text{ lbs plant biomass}$$

$$200,000 \text{ lbs plant biomass} / 10 \text{ years} = 20,000 \text{ lbs plant biomass per year}$$

B. Is this a reasonable quantity of biomass production for dryland cover crop systems?

- Reasonable range of biomass for dryland production ~ 1,000lbs – 8,000 lbs (Engel et. al., 2017)
- A ~2 ton/acre threshold of biomass needs to be met before SOM starts to accumulate, and below which SOM is lost

Appendix

The active learning intervention was comprised of this worksheet.

Practice calculating SOM change

Instructions: Complete the following word problems. The questions increase in difficulty. Work these problems as completely as possible. If you are stuck, or don't know what to do next, **indicate where and explain** why you're stuck. (What questions do you have / what information do you need to know in order to proceed). Please document this process in writing. Discuss with peers to help get unstuck and complete the problem.

1. A farmer claims to have increased their soil organic matter (SOM) by 4% over 10 years. Focus on the top 6" of the soil, with an acre furrow slice of soil weighing 2,000,000 lbs. Approximately how much cover crop biomass would need to decompose **per year** in order for this change to occur, assuming a 50% conversion rate from residue biomass to SOM? Is this a reasonable quantity of biomass production for dryland cover crop systems?
2. A) A farmer claims to have increased their soil organic matter (SOM) from 1.5% to 2% in one year, in a field that has been in continuous wheat. Focus on the top 6" of the soil. Approximately how much plant biomass would have needed to be added the previous year in order for this change to occur? Since the field is in continuous wheat, how much grain yield would support this claim? Is this a reasonable quantity? This time, focus on calculating this estimate by accounting for differences in residue C content and SOM C content.

SOM is typically about 58% carbon. For easy figuring, say 60%

The harvest index of most crops is around 40% (usually a little lower for cereals and oilseeds, and a little higher for pulse crops but consider it 40% for all crops)

A 6-inch acre slice of soil weighs about 2,000,000 lbs

~30% crop residues wind up as SOC

- B) This calculation has been simplified, crop residues take multiple years to fully decompose and any increase in SOM does not solely come from last seasons inputs. How could this increase in SOM otherwise be explained?

CHAPTER FIVE

UNDERGRADUATE STUDENT PERCEPTIONS OF FOOD-SYSTEM SUSTAINABILITY:
A GROUNDED THEORY OF THEIR PROCESS OF RECKONING

Contribution of Author and Co-Authors

Manuscript in Chapter Five

Author: Charles Watt

Contributions: I conceived the study, collected and analyzed data, and wrote and revised the manuscript.

Co-Author: Mac Burgess

Contributions: Contributed valuable discussion regarding conceptual and practical components of this research. Assisted first author with editing and revising.

Co-Author: Carrie Myers

Contributions: Mentored first author with study design, implementation, analysis, and interpretation. Assisted with editing and revising.

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*This chapter is formatted to meet formatting requirements for this journal.

**Undergraduate student perceptions of food-system sustainability: A Grounded Theory of
their process of reckoning**

Charlie Watt, Mac Burgess, and Carrie Myers

Abstract

Despite the perceived importance of sustainability in food-systems, students lack depth to their understanding of sustainability concepts. Definitions of food system sustainability are variable and deeply rooted in context, which pose challenges to effectively engaging students with the nuances and complexity inherent in the terms meaning. This study utilized grounded theory methods to explore how students made sense of concepts related to food system sustainability and how they apply these concepts in their life. The major factors contributing to how undergraduate students think about food-system sustainability are their life and educational experiences, their background knowledge, their prior areas of interest, and the perspective through which they view the system. Each of these factors influence each other and converge into a specific context where a student displays critical-thinking and meaning making to ultimately inform their perception of sustainability for any given system or issue in question. Student with less experience and knowledge hold more black and white notions of sustainability while students with more experience and knowledge generally hold more dynamic perceptions of sustainability. The pedagogical implications of this study highlight the value of active learning principles when designing curriculum and instruction. Engaging students in a diversity of food system settings through experiential learning and field trips are an excellent way for students to deepen their understanding of sustainability concepts.

Introduction

Despite recent efforts from academic institutions to engage undergraduate students in solving food and health system challenges, student perceptions and interpretations of sustainability remain unclear and ambiguous (Buckley, 2019). Emphasis on environmental awareness has led to the integration of sustainability in curriculum and driven development of new degree programs. With sustainability concepts gaining more prominence in undergraduate education, students are getting more exposure to the complex, context dependent, wicked sort of problems inherent to food system challenges (Rittel & Webber, 1973; Valley et al., 2018).

Despite the perceived importance of sustainability in agriculture, students still lack depth to their understanding of sustainability concepts (Williams, 2000). Many interpretations of the term exist (Bonnett, 1999; Buckley, 2019), and undergraduate student perceptions of sustainability are highly variable and often inconsistent with peers' definitions and definitions found in the literature (Behm, 2011).

Sustainable food systems undergraduate degrees have emerged from the call from society to produce leaders who are equipped to solve the inherently complex food system challenges of present and future (Valley et al., 2018). They are designed to present learning opportunities that meet this challenge by emphasizing systems thinking, multi-, inter-, and transdisciplinary perspectives, experiential learning, place-based learning, integration of teaching and research, and collective community partnerships and action (Andrée et al., 2016; Ahmed et al., 2017; Valley et al., 2018). Asking questions about the process of how students understand sustainability holds important implications for measuring the effectiveness of sustainability pedagogy and curriculum. Despite the increased use of sustainability concepts in educational

contexts and the rise in sustainable agriculture degree programs, traditional methods of outcome assessment do not seem adequate to measure the depth of student understanding, evaluation, and perceptions regarding food-system sustainability. While students are educated about sustainability in specific contexts of courses, which predominantly utilize disciplinary approaches to content and problem solving, examining the process of how undergraduates make sense of their academic understanding of sustainability to evaluate real-world food-system sustainability challenges centered around farming hold important implications to pedagogy and student learning. Strengthening our understanding of how students perceive applied food-system concepts will allow educators to design learning opportunities that draw upon methods that are meaningful to students.

As the term sustainability has gained prominence in everyday social, political, and educational discourse, it has come to manifest meaning primarily in ecological, social, and economic domains (NIFA, Oskamp, 2002). This contributes to the complexity and ambiguity of the term and thus presents challenges to teaching these concepts. The Burns Model of Sustainability Pedagogy engages 5 key dimensions to present a holistic approach to teaching sustainability: content, perspectives, process, context, & design (Burns, 2009). An approach to teaching and learning about sustainability that necessitates a focus from each of these dimensions harkens on the notion that a student needs diverse learning experiences to shape their perceptions of sustainability (Burns, 2009). Engaging in each of the key dimensions ensures that students gain exposure and have the opportunity to grapple with the notion of sustainability over a range of learning environments that call upon differing levels of cognition and high order thinking.

Reflection is also an important tool to develop student leaders in the field of sustainability (Burns et al., 2015).

Although interest in sustainability has grown across a broad range of academic disciplines, this research explores perceptions of sustainability from a food systems perspective. Sustainable food systems undergraduate degrees have emerged from an increasing global focus on environmental awareness and ecological design in food system management (Burns et al., 2015; Burns, 2012; Burns, 2009; Valley et al., 2018). The way that sustainability is taught in discipline-specific contexts does not align well with the need for students to emerge from university education as leaders ready to solve complex food and health challenges (Ahmed et al., 2017). Because of the complexity and contextual nature of sustainability (Behm, 2011; Bonnett, 1999; Buckley, 2019), pedagogical approaches must integrate the most current research and understanding of effective teaching to adequately meet the needs of students. These approaches must center around student-centered and active learning principles (Galt et al., 2013). Adopting these principles as the foundation of classroom management will be key to successfully implementing a pedagogy that utilizes teaching approaches such as transdisciplinary thinking, experiential learning, and community engagement (Andrée et al., 2016; Ahmed et al., 2017; Valley et al., 2018). There is consensus in the literature about the value of involving the learner in the active processing of new information (Ismail & Groccia, 2018; Mckeachie & Svinicki, 2014).

While common pedagogical themes emerge from the literature on teaching sustainability (Burns, 2009; Burns et al., 2015; Valley et al., 2018), traditional methods of outcome assessment do not seem adequate to measure the depth of student relationships to sustainability. This has led

to efforts that aim to understand more nuanced outcomes of sustainability education through student reflections (Whalen & Paez, 2020). More opportunities exist to get creative in finding qualitative ways to measure how students perceive and evaluate sustainability in a food systems context. The goal of this research is to develop a framework of how undergraduate students come to reckon food system sustainability in their lives. Deepening our understanding of how students evaluate sustainability has valuable teaching and learning implications in higher education and beyond.

There is an overwhelming call for a diverse learning experience to adequately shape students' understanding of sustainability. Sustainability can have many definitions for its' many applied contexts, and this, in part, adds to the complex nature of its meaning and how students reckon its meaning in the context of their own lives (Behm, 2011; Buckley, 2019).

If we are designing university education to prepare leaders to engage in complex challenges that are inherent to our food system, it will be important that undergraduate students have a comprehensive understanding of sustainability and the many contexts that it applies to. In order to teach them effectively, getting a better understanding of the process in which they reckon sustainability in their own lives will be crucial to designing curriculum and pedagogy to meet this challenge.

Materials and Methods

Grounded theory is a research approach used to understand how a certain aspect of the social world works. Further, we are operating under a constructivist paradigm as we are interested in the meaning of sustainability for each participant and what experiences and social contexts have formed these perspectives. The grounded theory approach is appropriate because

this study aims to understand the process in which people make sense of food system complexity and how they come to evaluate sustainability. This type of qualitative research serves to yield a model in with which to understand important mental/cognitive and social processes involved in a students' reckoning of sustainability. This has important implications for future teaching efforts in undergraduate education.

Statement of Positionality and Reflexivity

As a graduate student in plant sciences and education, with research and teaching duties on MSU's student organic vegetable farm, the first author has spent a lot of time and energy thinking about concepts of sustainability from not only the student and teacher perspective, but a deep personal connection to the concept and what it represents. I would even describe my own understanding of food-system sustainability as *under development*. This affords me an empathetic perspective to students who are struggling to grasp concepts of sustainability in real-world contexts. This quality will allow me to relate to and establish a rapport with study participants. I ran with Charmaz's (2014) idea that the researcher co-constructs findings with study participants. It is also important to note that I may have personal relationships with some study participants, however, I do not find this fact to interfere with gaining quality insights from our interview proceedings. On the contrary, I found having prior relations with a participant often led to more intimate and detailed interviews. Because I have relationships and shared experiences with study participants, I will be cognizant of any biases I may bring to the data collection and data analysis process.

Site Selection, Sample, and Sampling Procedures

Since we are interested in learning how students who have potential to become future food-system leaders understand concepts of sustainability, and the ways that learning on campus farms contribute to this, we targeted students who were directly or indirectly associated with Montana State University's (MSU) campus vegetable farm, Townes Harvest Garden (THG). Our sample included students who were enrolled in the Sustainable Food & Bioenergy Systems (SFBS) classes at Montana State University (MSU) (n=8), students who were involved in Towne's Harvest Garden (THG) (n=10), or students who have graduated from MSU having spent time in SFBS or at THG (n=2). The SFBS degree parameter is useful because students will have familiarity with food-systems challenges related to sustainability. Our typical case purposeful sample includes 20 participants. Of the 20 students interviewed, only 5 students did not have any direct farming related experiences.

Participation was solicited by direct invitation (to those already associated with THG), or from an announcement made in an introductory SFBS course (SFBS 146). Many of the students who volunteered from this announcement had upbringings related to farming or sustainability, and thus their participation probably reflects a prior interest or experience in this subject matter.

Data Collection Strategies

The first author conducted semi-structured interviews to collect data on undergraduate student perceptions of food-system sustainability. Interviews began by reviewing a standard consent document that was approved by MSU's IRB (Appendix; Form A). The interviews only commenced once verbal and signed consent was attained from each participant. The semi-structured nature of the interviews allowed for basic questions to guide participant responses

(Table 1). This method also allowed for depth and nuance to be measured by adapting the conversation to address salient points determined by the researcher. I followed Charmaz's (2014) constructivist approach that emphasized flexibility and highlighted the multiplicity and complexity of world views. This was important for the organic development of a conceptual model that described student processes. After informed consent was reviewed and any identifying information was conveyed, the interview sessions were audio recorded with the researchers iPhone and stored on a password locked device (iPhone and laptop). The researcher also had pen and paper to take notes but primarily relied on audio recording transcription for data analysis.

Table 1. Interview questions that address the research questions driving this study.

Research questions	Interview questions
How do undergraduate students in the SFBS degree program at Montana State University define food-system sustainability?	Define sustainability in your own words.
What life and educational experiences have contributed to their understanding of food system sustainability?	What are some life experiences that have helped develop your understanding of sustainability? Educational experiences? What, if anything, has changed your mind about sustainability?
How do they use their knowledge and experiences to evaluate food-system sustainability in real-world contexts?	How do you measure or evaluate food-system sustainability? What are the most important components of sustainability? Why are you motivated to work in food-systems / towards sustainability? How do you go about analyzing the tradeoffs and how do they affect decision making?

Data Analysis Strategies

Data was analyzed according to Creswell & Poth's data analysis spiral. Steps included: managing and organizing data, reading and memoing emergent ideas, describing and classifying codes into themes, developing and assessing interpretations, and representing and visualizing the data (Creswell & Poth, p. 187, 2018). I specifically followed Charmaz's (2014) approach to

coding that included initial coding to identify emergent themes and then describing links and relationships between themes. This supported our attempt to understand the process as opposed to explaining it (Creswell & Poth, 2018). Once the first interview was conducted, the researcher began to analyze the data using a constant comparative method so that subsequent interviews could be conducted and analyzed with continual regard to emerging themes and concepts (Creswell & Poth, 2018, p. 85). For example, in early interviews it was clear that when students were asked about life experiences that influenced their understanding of sustainability, they cited moments where their minds were changed and new beliefs were adopted. This prompted the researcher to include questions explicitly asking students to recount specific examples of when their minds were changed, and intentionally eliciting the idea of tension between old and new beliefs was used to encourage students to recall these powerful moments that emerged in different areas of their lives. Simultaneous data collection and analysis also encouraged the researcher to produce memos and themes that described the values, beliefs, and assumptions that underlie study participants' perceptions of sustainability (Creswell & Poth, 2018), which were subsequently used to construct a theory that describes the processes that students use to evaluate food-system sustainability. This inductive approach led to the development of a visual model of how sustainability is evaluated amongst study participants (Figure 1). These strategies were chosen to capture the multiplicity and complexities inherent in student perceptions as they construct their own notions of sustainability (Charmaz, 2014; Creswell & Poth, 2018).

Methods of Achieving Authenticity, Trustworthiness, Credibility, and Transferability

I ensure trustworthiness in my study by tending to credibility, confirmability, transferability, and authenticity. For credibility, I used the zig zag method of data analysis

common in grounded theory studies (Creswell & Poth, 2018). Using this method, as well as member checking, ensured that themes reported in my findings accurately reflect participant perspectives. Confirmability is strengthened by substantiating my discussion of participant perceptions with real-world examples of food-system sustainability. I ensured the transferability of these research findings by utilizing thick descriptions of, or closely detailing, the context that support a participants' view of sustainability. In doing so, the resulting conceptual framework explains the process of understanding sustainability from the participants' perspective, which can be used as a framework to guide other research inquiry or inform pedagogical reform. I also ensured that my sample reflected the targeted population and grounded resulting discussion in a context that is relevant to teaching sustainability in undergraduate education. Authenticity was established by maintaining reflexivity in my positionality as a researcher. I recognize that I am not far ahead of study participants in age or experience and admit my perceptions of sustainability are still in development as well. Relating to the student's process of understanding the nuance and complexity of a concept such as sustainability will enhance my ability to authentically portray how study participants perceive food-system sustainability.

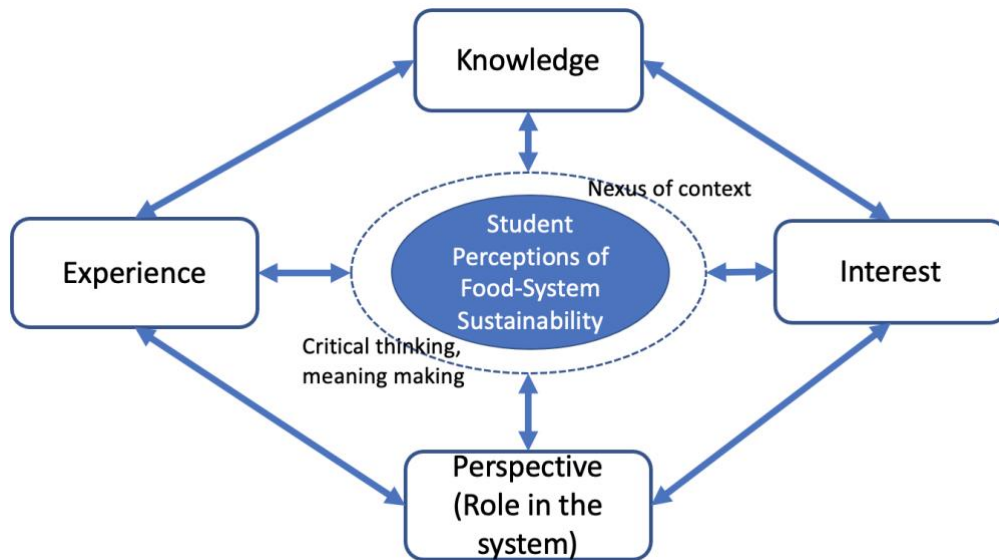
Results and Discussion

Analysis of interview transcripts reveal how people with different levels of knowledge and experience understand and think about concepts regarding food system sustainability in distinctive ways yet use a common framework for making sense of things. All study participants acknowledged the complexity and ambiguity of the term and agreed that working towards food-system sustainability requires a holistic approach. When asked to provide a definition for sustainability, most students cited sustainability as existing within three distinctive domains:

environmental, economic, and social. This likely emerged from discussions in 100-200 level coursework in the SFBS degree program where these definitions were discussed.

Overall, perceptions of sustainability were informed primarily by their life and educational experiences, personal interests, background knowledge, and perspective (Figure 1). These emergent themes were present in all study participants and guided how they thought about and evaluated the concept of sustainability. The interplay of these factors formed a nexus point of critical thinking and meaning making in order to evaluate sustainability in real-life contexts.

Figure 1. Conceptual model of the primary factors affecting undergraduate student perceptions of food-system sustainability.



In general, less experienced and knowledgeable students held fixed notions about sustainability while students that were further in their program and/or held more practical food-system experience hold more dynamic conceptualizations of sustainability. Similarly, younger students held more attachment to existing beliefs while students with more experience and knowledge were more fluid with their belief construction. This is partially due to an

acknowledgement of the uncertainty, complexity, and context specific nature of sustainability, paired with an acknowledgment that their own limited knowledge and experience prohibit them from really “knowing” anything with certainty. For example, one student mentioned how they came to THG with certain beliefs they’ve gathered from reading books, only to realize that what they previously deemed as unsustainable actually made a lot of sense for the operations at THG. This is a powerful example of how experience can complement conceptual understanding to develop a more nuanced perspective. Similarly, as students gained more experience and knowledge, their definitions of sustainability expanded beyond mention of just the three major pillars and reflected an understanding that emerged from what they found to be the most important aspects of sustainability.

Factors Affecting Student Perceptions of Sustainability

Life Experiences.

All students drew upon life experiences to make sense of concepts related to sustainability. On a surface level, holding farm-related jobs seemed to deeply influence their understanding of food production. One student noted how having worked on multiple different farms has broadened their perspective and dispelled many misconceptions he had about sustainability. He mentions this realization after having worked at his second farm: “it was a big sort of mind shift because over there we didn't use tractors because we didn't want to use fossil fuels, you know. But now I see how much more efficient we're able to be at Towne's, and the fact that we're actually able to make a profit.” In this case, having a broad range of experiences in different parts of the food system has informed a more refined understanding that acknowledges other dimensions of sustainability beyond environmental impact.

Beyond job experience and looking more deeply into how sustainability has been integrated into their lives, many students acknowledge lifestyle choices and family upbringing as having a tremendous impact on the way they engage with sustainability topics. Many students remarked that having parents who gardened or recycled were some of their first connections to food and sustainable practices. One student describes a profound moment when they realized how far we've departed from sustainable food-systems after having conversations with their grandparents and realizing how much more connected they were to their food, and how quickly that's changed over just two generations. In this way, connecting to elders and listening to their stories resonated with not just this student, but other study participants too.

Another student credits their upbringing in an indigenous household for seeing food-system sustainability in a relational way, in which our relationship with the land and the people in the food systems must supplant our current unbalanced, market-driven understanding of sustainability. They describe how food can not only be healing on a physical level, but sharing food with each other can be healing to relationships and a meaningful way to connect with people. For them, institutional approaches to research and education in the realm of sustainability fail to ask deep enough questions that will lead to meaningful change. While data-driven approaches to food-system management are valuable, they risk dehumanizing critical components of our food system and over-simplifying how we address sustainability on a larger scale.

Many students spoke of their engagement in the topic as emotionally wavy, or taxing. One student likened his role in the food system to his role in his band. Through learning to play music in harmony with people, he better understands the collaborative and interconnected nature

of food system solutions. Making connections to their life experiences has deep impacts on how they engage with concepts of food system sustainability, especially when connection elicit emotions (Quinlan, 2016). This student goes on to explain that sustainability has implications beyond eating healthy, “for [their] physical form, but also [their] spiritual existence.”

Educational Experiences.

Ubiquitously apparent, educational experiences played an important role in informing student thoughts on sustainability. Multiple students mentioned exposure to gardening in elementary or high school programs initiated their engagement with topics surrounding food system sustainability. This was formative to the development of their personal and academic interests later in life. Other students describe undergraduate courses as being a place to engage in these conversations. One student says, “I feel like any SFBS class I've had has been a good sounding board for me... Maybe not filling me with new ideas and hopes but reminding me of practical ways to go about achieving those [results] vs impractical.” This nod toward staying grounded in practical solutions demonstrates a certain maturation – not wanting to be swept in hopeful, unrealistic, thinking. Another student agrees that, “it’s important to be 100% realistic about the problem.” Many students acknowledge that being around peers and professors has helped them dig deeper. “It’s through conversations with my leaders that I've been able to have a more nuanced perspective.” These statements indicate a shift from perceptions that are black and white to a more acutely informed perspective of sustainability.

For students who did not grow up immersed in agriculture or who lacked direct connection to food production systems, field trips through MSU provided them with invaluable opportunities to connect with and learn from a diversity of food system workers. Not only do

field trips provide students with practical examples of sustainability practices in-use, but they also allow students to connect theoretical concepts learned in classroom setting to real-world examples. Often, it is apparent to students that even when farmers may not embody sustainability in the same way, they can still share sustainability goals nonetheless. This helps build a context-driven understanding of sustainability and promotes acknowledgement of nuance and uncertainty over fixed notions. Students with more experience and knowledge more readily acknowledge these nuances while younger students often evaluate the sustainability of a particular system dichotomously.

Similarly, many students mention their experiences at Towne's Harvest Garden, MSU's student organic vegetable farm, as having a noticeable influence on how they view and interact with the food-system. One participant says, "by getting plugged in at Towne's, I learned how to ask those sorts of questions." They are referring to questions that are relevant to a specific context and provide meaningful implications to improving efficiency, rather than questions that broadly addresses sustainability in ways that may not apply to every situation. The learning farm has been a place, "where [students are] around people who are much more intelligent and much better system thinkers, and have been plugged into this sort of eco system longer." Another student describes being lost to their ideals before experiences at Towne's Harvest Garden have brought them back down to earth to view problems and solutions in a more practical manner. For some, THG is place where they are introduced to important concepts and for others, THG is a place where deeper understanding and practical skill can be nurtured and developed. Every student who was employed by THG and spent a full growing season or longer on the student farm credits their experiences there as pivotal to their development as a student.

Background Knowledge.

The existing background knowledge that students hold has an important influence on how they think about sustainability. It helps them to make sense of the concept broadly and when they evaluate the sustainability of specific real-world examples. One's existing knowledge is a direct and indirect result of one's life and educational experiences. The more background knowledge they held (here referring to coursework and food-system job experience), the more they viewed components of sustainability as being interconnected. Students also displayed a metacognitive awareness of how their perceptions have evolved with the more knowledge they've gained. Students referred to points earlier in their academic careers when concepts of sustainability were more black and white, had more definitive and absolute principles. Earlier in the program, the students admitted to holding simplistic notions of sustainability, having a tendency to think solutions were one-dimensional. The participant mentions [of their earlier selves and peers in 100-level classes], "they're not taking into the interconnected nature of the problem... the most important thing to me is that we like to stay grounded in how complex the problem is." This increase in background knowledge that reflects this matured perspective has come from both life and educational experiences as previously mentioned.

We see their background knowledge informing their perspective in the way that they define food-system sustainability. The students with the least coursework and experience related to food-systems drew most directly from their classroom lessons and readings. Most upper division students demonstrated a point of view that reflected a complex and dynamic understanding of the concept that integrated their personal beliefs with their classroom teachings. The idea that you, "can't look at a single metric," to judge sustainability demonstrates that their

perceptions have developed to portray the multiplicity of ways that sustainability can be measured. Students view their own knowledge base as both an enhancement and a limitation to their understanding of sustainability. They're aware of the progress they've made, but also exhibit a healthy realism in which they see how gaps in their knowledge also limit their depth of understanding in certain areas. In most cases, students acknowledged the need for sustainability to be addressed holistically.

Personal Interests.

While unsurprising, it is worth mentioning that student's prior areas of interest play an important role in how they think about food-system sustainability. Areas of interest are partially informed by one's experiences and background knowledge, and these prior interests dictate what aspects, or through what lens, of sustainability they prefer to engage in. One student explains how their primary focus on environmental issues in food-system sustainability is reflective of their interest, while another student admittedly focuses on social aspects. This does not mean they are unaware of other pillars/components sustainability, but this indicates how they rely more heavily on familiarity with what they have existing interest in.

The personal interests of students aren't typically affiliated directly with food-system sustainability. Yet when asked to reflect on how they make sense of sustainability concepts, they tend to make connections with their existing passions. This is a powerful example of how important meaning-making is to a student's ability to make sense of such a complicated concept (Kraus, 2012; Willingham, 2009).

One student discussed how their passion for travel illuminated the importance of cultural context when generating solutions in the food-system. Another student repeatedly related issues

of food-system sustainability to their musicianship. They likened their role in the food system to the roles they have in a band. In a similar way that members of a band need to be selfless to better serve the bands overall sound, from being in a band he's gained an understanding that, "makes [him] more sensitive when making decisions that don't help work towards a sustainable future." Drawing upon existing interests can have valuable implications that help students think about food-systems in more meaningful ways.

Perspective or Role in the System.

The last major theme that emerged from student interviews was what perspective they inhabited- what they perceived their role in the system to be. By this I mean students identified the tendency to approach challenges of sustainability differently depending on if they view them through the lens of, for example, a producer or consumer. At this age, everybody has experiences from the lens of a consumer. A few students mentioned felt that they felt limited in their capacity to work towards sustainability from a consumer perspective due to the financial limitations of being a college student. Some students made deliberate sacrifices to purchase organic food, while others could not justify the price, especially because they believed the organic label did not necessarily represent sustainability. Either way, all students engaged in thinking about sustainability from the lens of a consumer.

Many students that were interviewed also had experience farming or in some other setting in the food-system (I.e., food banks, co-op grocery stores, restaurants, etc.). These students indicated how their perspectives have been expanded, complicated, by their experiences in other corners of the food-system. In fact, navigating various roles in the food system present challenges when tasked with evaluating the sustainability of real-world examples. Younger

students mentioned the tendency to shut-off, or rely primarily on one perspective when making decisions because it gets complicated when they try to account for everything they know. This perhaps indicates an area that could be further developed in the way that undergraduate students think about sustainability. They acknowledged the multiplicity of how sustainability manifests in the real world, but they struggle to navigate this multiplicity when making food-related decisions in their life. A few students demonstrated the capacity to consider multiple perspectives at once (& deal with conflicting information-to be mentioned in discussion). These were the participants who had the most experience in food-system settings.

A Grounded Theory Model of How Students Think About Food-System Sustainability

This study sought to understand how undergraduate students at MSU understood the concept of food-system sustainability. Ultimately, student interviews reflected the notion that sustainability is a Gordian knot of sorts, affected by many different environmental, economic, and social factors.

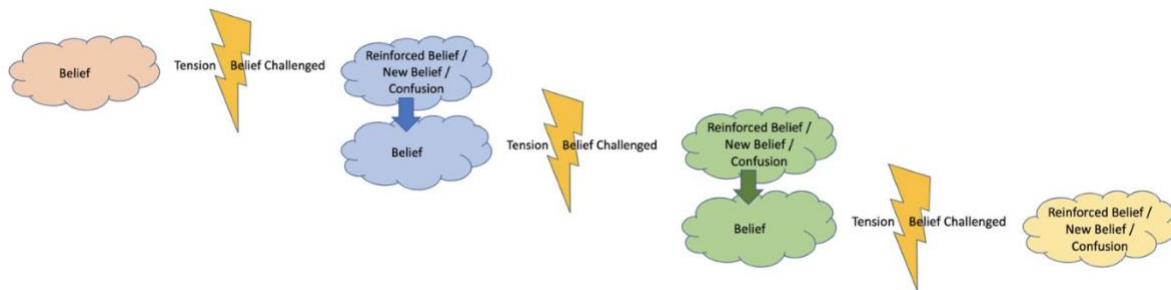
The findings revealed in this study echo many of the sentiments found in the literature regarding perceptions of sustainability. While students view sustainability as a vague term that can take on different meanings depending on the context (Bonnett, 1999; Behm, 2011; Buckley, 2019), this research elucidated a process in which students make sense of and evaluate sustainability amidst the inherent ambiguities. The major factors contributing to how undergraduate students think about food-system sustainability are their life and educational experiences, their background knowledge, their prior areas of interest, and the perspective through which they view the system (Figure 1). Each of these factors influence each other, and form the basis for how they think about sustainability. Each of these factors converge to inform

an overall perception of sustainability that can vary depending on the context of the situation.

These factors form the substance of the thoughts regarding sustainability, but they must converge into a specific context where each student displays critical-thinking and meaning making to ultimately inform their perception of sustainability for any given system or issue in question.

There are qualitative differences in how students with varying experience and knowledge levels engage with concepts related to sustainability. Inexperienced students that are earlier in their academic program have more attachment to beliefs and hold more black and white notions of sustainability. While there can be acknowledgement of complexity and uncertainty, learning in this stage can be characterized as overwhelming, emotional, and intense. Students need to adopt, or try on, certain beliefs/philosophies while they're building a knowledge base. The learning process is often a linear; when an existing belief of concept is challenged, the process of making sense of the tension leads to the reinforcement of the existing belief, the adoption or creation of a new belief, or confusion. It is from that updated understanding where more tension interacts to form a linear progression that deepens their understanding of sustainability. Many Experiential Learning Theory scholars have alluded to this idea that, as the learner is transformed by resolving conflicts in their worldview, they continually increase their readiness, or raise their intellectual bar that serves as a foundation for continued learning (Kolb, 2014).

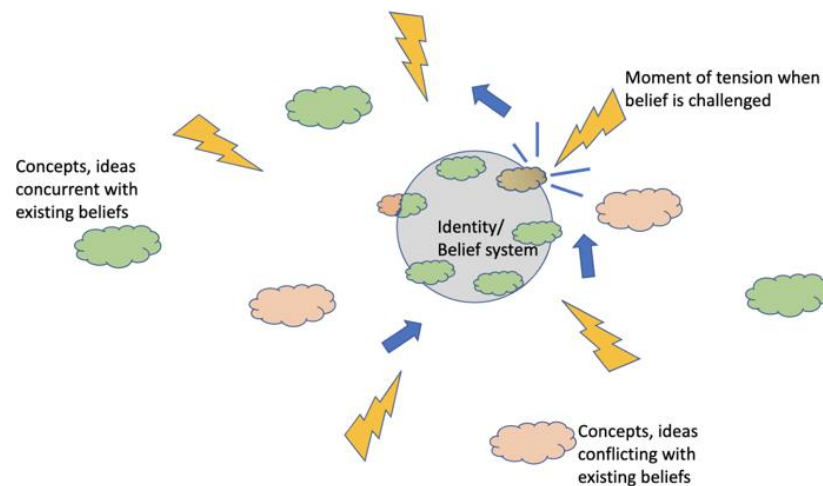
Figure 2. Conceptual model of the process of learning or gaining new knowledge for young / inexperienced students.



As students gain more knowledge and experience, the learning process becomes more dynamic and personal, following more of a cyclical pattern in the evolution of their understanding. In this stage, an identity or belief system around sustainability emerges that is an integration of their existing knowledge, experience, and beliefs. It is through the lens of this identity, taken together with the context of a situation, that they interact with the food system. As they navigate a sea of ideas and perspective concurrent and conflicting with their own existing perspective, they have moments of tension where they engage with new information and must integrate it into their foundation/identity. There is often a metacognitive awareness of a complexity that can't be grasped, that limitations in their own understanding prohibit certainty ever being attained. Within this idea nothing is absolute and students may adopt certain components of an idea while dismissing others. While daunting, a mature learner is motivated and humbled by this uncertainty to remain open-minded to new or conflicting ideas. Where feelings of fear and ineptitude often characterize students early in their understanding of food-system sustainability, a mature student realizes that a sustainable future relies on an

interconnected community that is more solutions oriented than problem oriented. This inspires them once again.

Figure 3. Conceptual model of the process of learning or gaining new knowledge for mature/experienced students. Depiction includes belief bubbles that are half green, half red, or as a mix between the two colors. This represents the notion that students may latch onto, or accept, certain components of an idea or concept, but may reject others.. Or that after moments of tension, there is a reckoning process in which it takes time, and usually reflection, for a belief to become fully integrated into their belief system.



The tendency for students to draw heavily on their personal experiences to inform their understanding of food-system topics have tremendous implications on curriculum and pedagogy in undergraduate settings- especially for Land Grant Universities that focus on applied agricultural science and food-system challenges. Our findings that elucidate the qualitative differences between students in various stages of their learning process are reminiscent of Perry's scheme of intellectual development, where students move through the stages of dualism, multiplicity, relativism, and commitment in relativism (Kurfiss, 1994). As teachers, if we can recognize where in their intellectual development individual or cohorts of students are, we can

use an adaptive approach to teaching that engages students in ways that are most relevant to their cognitive stage.

The College of Agriculture at MSU has a network of agricultural research centers throughout the state, including several farms close to campus in Bozeman. That is the site of Towne's Harvest Garden, the student vegetable farm where SFBS students take a practicum course and where some continue to managerial positions on the farm. Study participants that have gone through the practicum course and now work at the farm clearly described their variety of educational and farm-related job experiences as having strongly influenced how they view sustainability. It is through engaging with community stakeholders, playing various roles in the system, and constantly having to adjust their perception with new knowledge gained that they are able to see sustainability as being a fluid concept. Increasing experiential learning activities and opportunities to think through academic exercises from various roles in the system (producer, consumer, stakeholder, etc.) will increase their problem-solving capacity in applied food-system contexts (Niewolny et al., 2012).

The value of deepening student understanding of food-system concepts will have positive impacts on their propensity to solve complex problems inherent to food-system sustainability upon graduation (Rittel & Webber, 1973; Valley et al., 2018). The approaches to on-farm education that are taken at Towne's Harvest Garden reflect student-centered and active learning principles (Burns, 2009; Andrée et al., 2016; Ahmed et al., 2017; Valley et al., 2018). We now have the challenge of designing approaches to traditional classroom instruction that draw upon the same principles that on-farm learning does. It is not realistic to open the farm doors to every single student, so we must encourage students to draw connection and meaning by bringing the

active learning classroom to them. For example, using case studies or inquiry-based-learning can be used in traditional classrooms to enhance student engagement.

Another way to enhance sustainability education, along with experiential learning, is to encourage student reflection and have them explore a diverse range perspective (Burns, et al., 2015; Whalen & Paez, 2020). This data suggests that prior areas of interest and background knowledge play important roles in their understanding of food-system concepts. If we can encourage student to personalize their educational experiences through reflection exercises and prompt them to draw meaning from academic concepts, then we will be able to enhance their understanding of sustainability. It is how they draw from their experience, knowledge, interest, and perspective that their perception of food-system sustainability emerges.

Conclusion

Undergraduate students at MSU held relatively nuanced and complex perceptions of food-system sustainability. They exhibited an understanding that is rooted in context and views sustainability as existing on a spectrum. They were able to critically analyze tradeoffs within a system in order to evaluate general sustainability. In large part, students drew from experiences, interests, background knowledge, and their perspective to inform their perception. While these factors generally enhanced their perceptions, students felt that limitations in knowledge and experience confine their understanding. Efforts to understand how they find sustainability relevant and meaningful to their lives have important implications for undergraduate education. Expanding experiential learning opportunities will certainly enhance food-system literacy. When this can't be done by bringing students directly to the farm, finding creative ways to appeal to their prior areas of interest will serve to promote meaningful relationships with these concepts.

Teachers can do this even in classroom settings through reflection and prompting students to explore diverse perspectives. These all interact to inform a student's background knowledge. Student perceptions of food-system sustainability emerge when they think critically about how all these factors interact.

Teachers can use this model to help students grasp other complex concepts such as globalization or intercultural collaboration. Making students aware of their own cognitive tendencies can provide powerful heuristics for students to use in self-directed settings that help them become more efficient in their learning processes. Even in classroom settings, discussion of metacognition with students, and intentional activity design from instructors that calls upon engagement with different domains (i.e., experience, background knowledge, prior interests, point of view) can enhance students ability to mature to more dynamic conceptualizations of complex issues in the food-system. Future research exploring how students understand different concepts could lead to the development of models that describe other domains that exist when students are making sense of ambiguous and nuanced concepts in other academic fields.

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CHAPTER SIX

CONCLUSION

This chapter includes a summary of emergent themes from my dissertation, reflections on how I think we might best address the challenges currently facing humanity, and a description of my personal conception of what it means to learn.

Summary: Diverse Approaches in
Agriculture and Education for Enhanced Learning

There is an inherent complexity to agricultural and social systems that leads to difficulty comprehending them and generating solutions in these settings. It is apparent from my interdisciplinary work that diversity is an important principle to improving land management and educational strategies.

Results from research on organic soil fertility (chapter three) suggests that N concentration of amendments is an important predictor of crop yield and soil N. This is consistent with the idea that amendments with low C:N mineralize N more rapidly than high C:N amendments (Guster, 2005; Schroth and Sinclair 2003), yet also supports Marshall et al. (2016) findings that the form of N (organic v. inorganic, soluble v. insoluble) is more important than concentration alone, as the low C:N amendments tested in our study also had higher concentrations of inorganic N. However, this inference is limited in scope to short-term crop nutritional requirements, as our study occurred over two growing seasons. Our study sites have relatively high SOM levels (4-5%), so we can infer from the lack of observed differences between control plots and plots amended with compost and the small magnitude of difference

observed between control plots and low C:N amendment plots (blood meal, soy pellets), that adopting strategies that build the SOM levels using stabilized composts has the potential to enhance organic nutrient pools and nitrogen use efficiency in the soil, which is consistent with other studies (Chalhoub et al., 2013; Guster, 2005;). For the goal of supporting short term yields while simultaneously building SOM, I suggest using a diversity of inputs to meet these needs.

Engaging undergraduates throughout my research process also elucidated the value of integrating applied agricultural research into undergraduate pedagogy. Not only was my knowledge enriched by having to teach students production strategies and ecological principles related to my research, but engaging undergraduates in my process of scientific inquiry provided students the opportunity to apply concepts learned elsewhere in a real-world setting. Even if there was no data collected suggesting enhanced outcomes or content mastery, I witnessed first-hand the positive impact that including students in the research process can have on learning related attitudes and beliefs. The undergraduate student that chose to assist in my research as part of a practicum course assignment wound up becoming my research assistant and was hired to management staff the following year. It was clear, from conversations with them, that their experiences engaging in my research was one of the factors that inspired them to continue farming.

Chapter Four provides direct quantitative evidence in support of the utilization of active learning strategies, alongside didactic instructional methods, for improving high-order thinking and learning outcomes related to complex topics. Educators should be encouraged to utilize any means necessary to support student learning, this includes incorporating a diversity of instructional delivery methods as part of their pedagogical strategies.

Similarly, Chapter Five provides direct qualitative evidence that supports the use of experiential learning to enhance ways that students make meaning from their college experiences. The grounded theory model that emerged from 20 student interviews describes how students rely primarily on educational and life experiences, background knowledge, personal interests, and their perspective to inform how they think about food-system sustainability. Each of these domains are interconnected and highlight how meaning-making is a central component of a student's capacity to engage effectively with food-system complexity. Students that had the most mature understanding of sustainability concepts credit diverse learning experiences- from experiential learning, to dialogue with community practitioners, to self-directed inquiry- for their ability to draw connections between food system concepts and make sense of the context-dependent nature of sustainability.

Findings from each of these chapters demonstrate the value that diversity in educational pedagogy and curriculum has in building student capacity to grasp the diversity of agricultural concepts they're faced with as students and future food-system workers. From a farming perspective, in the face of uncertainty or ambiguity, my research shows that while certain soil amendments may be advantageous for specific situations, building healthy soils while maintaining sufficient crop yields requires a diversity of inputs.

Reflections: A Call for Radical, Systematic Paradigm Changes in Education and Agriculture

While not a new idea, and intuitive one for those who are observant of natural and social systems, it is apparent from my work that diversifying how we think about, engage with, and generate solutions in our agricultural and education systems will give us our greatest chance at a sustainable future. From deciding which organic soil fertility input to use in vegetable

production, to the kinds of methods we utilize in our quest for knowledge inquiry, to designing curriculum and pedagogy in an undergraduate setting, to the way our institutional decision-making apparatus operates, diversity serves to maintain a balance in the ways we solve problems. Balance is important because everything is connected, and the limited nature of human perspective hinders our capacity to fully grasp the implications of our actions. Further, acknowledgement of the dynamic nature of agricultural and social systems and commitment to remain open-minded are essential to our capacity to embody diversity. Adherence to fixed ideas and beliefs have exacerbated the rate in which we are losing cultural and biological diversity. Embodying diversity also serves to ensure we are efficient in our problem-solving. A synergy emerges when we allow a diversity of perspectives to collaborate towards common goals, just as a synergy of emergent behaviors arise when diversity is welcomed in soil systems (Dunkel et al., 2011; Lehman et al., 2020).

These suggestions could be applied on a mechanistic level to the way our educational and agricultural systems work towards sustainability goals. Yet, this would be shallow and ignore the ways in which our structures of power and economic systems are designed to undermine cultural and biological diversity (Maldonado-Torres et al., 2019). I am making a call for radical, systemic changes to the paradigm through which we view the world and engage in problem-solving. I do not see us moving towards a more sustainable future at the rate that is necessary under our current problem-solving apparatus.

It is not that agriculture is an inherently destructive act, it is that our models of agriculture have devolved to be extractive in nature and driven by profit. The dominant global culture purports the idea that human progress necessitates the separation of people from food production,

embodying the notion that “progress” is no longer having to worry about where you get food so that you focus that time on other endeavors. Let us not forget the etymology of *agriculture*, with human involvement being a defining feature in how we procure calories. Thus, a narrow conception of agriculture that focuses primarily on mechanisms of production and the biological and physical systems that support them is to neglect an essential element of agriculture.

Vygotsky would suggest that agriculture is a manifestation of human culture (Carson, 2016/2003). The utility of this separation (not implying conscious intent) is that it opens the door to industrialization and extraction. The quality of both our natural systems and our social systems erode when we replace agroecological principles with industrial approaches (Goldschmidt, 1978). The detachment of agriculture from the people who practice it has severed an intergenerational connection to the land and eroded meaningful cultural traditions embedded in food production. With the shift to commodity agriculture, entire societies have been forced to give up diverse, complex systems of growing food that relied on local knowledge and resourcefulness. Indifference to this vital connection between people and their food growing ways has allowed a system to emerge where human well-being and autonomy suffers in the name of reaching global efficiency and sustainability metrics. Once self-sufficient, many land-based peasant societies are now shackled by debt and coerced into practicing an agriculture that leaves them dependent on an agribusiness model devised by people with no local knowledge. An example of this can be seen in how global seed companies focus on singular varieties that are reliant on chemical weed control and fertilization as opposed to supporting a bioregional seed network that includes genetic diversity more relevant to local regions. Approaching agriculture as a solution to climate change through a purely scientific lens with a primary focus on top-down

environmental and market-based interventions ignores the cultural and social resources that have the potential to inform intelligent, well-suited solutions for a given location.

I believe the ways that agriculture can serve as a healing force are contextual. We should be wary of any silver-bullets promoted over broad scales. Generating solutions on a local level has potential to be more effective than broadcasting solutions from a top-down, concentrated agribusiness perspective. Since context (i.e., local system constraints, stakeholder needs, available resources etc.,) dictates appropriate intervention, local leadership and constituents are more adept at devising interventions given their familiarity with the system. When this is practiced, local knowledge and local needs become primary drivers in the development of systems that can holistically address all dimensions of sustainability- environmental, economic, and **social**- while still meeting metrics of productivity competitive with industrial models (Pretty et al., 2003). Small-scale, diverse vegetable farming plays an important role in our local problem-solving apparatus.

Perhaps my thoughts on the matter are best summed up by the Albert Einstein quote, “the significant problems we face cannot be solved at the same level of thinking we were at when we created them,” (paraphrased from Einstein, 1946; Calaprice, 2005). This implies a need for a new way of perceiving and interacting with the world.

So what does this mean on a personal and practical level? For me, this means critically examining the ways in which colonial power structures affect my understanding of the world: from the stories I believe in that describe the ways the world works, to the ways that I conduct knowledge inquiry. Relating back to the discussion in the introduction about the importance of elucidating philosophical assumptions that frame qualitative research- I am re-examining the

philosophical assumptions, or my personal beliefs about ontology, epistemology, axiology, and methodology, that frame my understanding of the world. For me, it is transformative just to acknowledge the impacts of colonization on my cognition, as Vygotsky so compellingly argues that cognition and consciousness are artifacts of culture (Carson, 2016; 2016/2003).

We also must examine ways in which institutions, such as publicly funded universities, embody a colonial mind-set (Richardson, 2018). While this was not a direct line of inquiry during my PhD program, I think there are pedagogical implications of this notion that directly tie to the theme of diversifying educational approaches for the enrichment of the student experience. A metaphor can be seen by thinking about the differences between western scientific ways of knowing and traditional ecological knowledge. Scientific Ecological Knowledge (SEK) values observation, quantification, and a reductionist approach to determining truth, similar to the way Behaviorists think. Traditional Ecological Knowledge (TEK) values relationality, holistic-thinking, and intuition as a means to understand the world, similar to the way Gestalt principles align. If we want to gain a comprehensive understanding of the ways that the world works, an integration of both perspectives can allow us to see the world more deeply than a myopic perspective would. Favoring one knowledge system over another limits our creative problem-solving capacity. However, similar to the way Behaviorist ideologies underlie American educational frameworks, academic institutions are structured to support western ways of knowing and don't give much credence to traditional ways of knowing. Given the often synergistic capacity of two complimentary components (as we see in Kolbs Experiential Learning Cycle, 1984), we would all benefit from a more balanced epistemological approach. Remaining open to alternative epistemologies gets at the heart of Barr and Tagg's (1995) idea

that, when institutions orient towards a learning-centered paradigm, the institution itself becomes a *learner* that is committed to helping students learn by any means possible. If we desire for our students to experience transformation, we must open ourselves to the idea that the future of education must also transform.

We must remember that at the heart of all educational theory is the desire for deep, life-long, and transformative learning to occur in both teachers and students. The chances for this are enhanced when people think about meaning and assign value to what they are engaging in (Kraus, 2012; Marx & Gates, 2016) and it reflects the cognitive principle that memory is the residue of thought (Willingham, 2009). It's not enough to get students to think about something, but how they think about something is just as meaningful (Willingham, 2009). Designing opportunities that encourage students to think about something and steering *how* they think about it is equally important. Often, we're clear what we want students to think *about*, but designing activities to elicit the *how* is difficult.

Waiting for individual educators to embody these changes is like shifting responsibility for climate change to the individual level as opposed to holding corporate entities responsible. I believe our best chance to solve problems related to our survival as a species is to demand systemic changes to our educational institutions that will embody adaptive, learning-centered paradigms.

The intersection of agriculture and education provide a powerful context for examining the value of learning-centered paradigms. Agriculture is an applied discipline that manifests as an integration of both life- and social sciences. As it draws from a variety of disciplines, it remains a complex field that is highly context dependent. As such, teaching agricultural concepts

requires a unique, holistic pedagogical approach to effectively convey the intricate interconnectedness that is characteristic of food-system studies. I want to provide concrete examples of how educational institutions might work toward these changes.

A practical example of how this paradigm operates would be creating opportunities for students to engage in the same material through differing modes of perception and processing, which can stimulate different ways to think about the material. In doing so, we can increase chances that students think as we intend them to. Robert Carson's (2002) *Ourstory* curricular framework is an excellent example of how teachers can guide students to think about meaning and relationality amongst concepts through structuring curriculum in a historical and social context. This framework embodies gestalt principles through use of story and by linking cultural motifs to help students build meaningful connections in traditionally separate realms of learning (Carson, 2002).

With an institutional responsibility for learning to occur, universities operating under a learning-centered paradigm could encourage the adoption of the most up-to-date research on teaching and learning. If teachers use methods that are at odds with current understandings of effective teaching methods, faculty would be discouraged from using them. Not only that, but faculty would be given resources to help *them learn* and better understand student needs. It would also require any graduate student on track to remain in academia to undergo educational coursework and to get practice. The differences in quality of instruction I received from courses in the Education department and College of Agriculture was quite apparent. Implementing mandatory training for educators in all disciplines would function to provide teachers with an

underlying organization to support their understanding of teaching, which ultimately would allow teachers to convey their course content in the most effective ways.

I think another way to encourage these gestalt-like structures of effective teaching would be to encourage more dialogue amongst faculty. In this way, teachers would have exposure to more patterns in teaching by having regular conversation with their peers. It would also encourage reflective practices which can help to improve teaching (Brookfield, 1995). Parker Palmer (1993) notes that surgeons and trial lawyers cannot conduct their work without being observed and challenged by others who know what they are doing. He laments on the fact that professors conduct their practice in private (Palmer, 1993). If teachers spent more time in dialogue with each other, they would have opportunities to form gestalt-like structures or patterns that deepen their understanding of effective practice.

A deeper personal understanding of teaching and learning, student development, and cognitive psychology would equip teachers with more “tools” to help their students gain knowledge and skills more effectively. Understanding gestalt-like structures in content and the relationality inherent in mental processing could be applied to the way that teachers engage and guide student learning. For example, linking material in an organized manner to elicit “positive transfer” could help students make connections between academic concepts. Or understanding the “Zeigarnik effect” on student motivation could help students with problem-solving or prepare for examinations (Hunt, 1993). Even the idea of grouping students to work on problems of varying difficulty could be just the trick to get student’s to “like” your class, as Willingham suggests that humans are more likely to engage in thinking when the problems are not too hard

and not too easy (2009). Just imagine your students as Goldilocks – as teachers we must search for the perfect bowl of porridge for them to sink their spoon into.

I would also like to make the call for more qualitative research to be deployed in applied agricultural science. As an applied field existing only in a cultural and social context, there is valuable insight to be gained from the types of questions that we can ask in qualitative approaches. The capacity to integrate qualitative research and quantitative research methods in agriculture not only increases the scope of questions we can ask, but synergistically increases our inference power as our understanding becomes more dynamic and nuanced. Powerful examples are seen in ecology as qualitative research is used to inform structured decision making processes, which can inform management interventions and resource allocation beyond quantitative and biological parameters (Robinson et al., 2019; Smith, 2020).

Personal Conception of *Learning*

My personal conception of *learning* draws heavily on Experiential Learning Theory. I have arrived here by integrating my interpretation of several teaching and learning theories with my first-hand experiences as a teacher and life-long student. It follows, then, that my definition echoes Kolb's notion that learning is a transformative process, is most meaningfully evoked when participating in various modes of engagement (including experience), and is situated in a complex and often intangible web of social influences that constantly requires the learner to calibrate [what they learn] to an inescapable, often subconscious existential undercurrent that is intrinsic to life. The last part echo's Jarvis's (2018) realization that the social context of learning is likely more complex than we acknowledge, and that learning is both experiential and existential.

I am naturally a reflective person, and being a graduate student during the COVID pandemic has prompted deep reflection on the significance and utility of my doctoral work. As it has been made clear, there has been a lot of disjuncture in my understanding of the way that the world works, particularly, our [societies'] path to creating solutions to the many crises we face, and my own role in generating solutions. Many ELT scholars have alluded to the idea that, as the learner is transformed by resolving conflicts in their worldview, they continually increase their readiness, or raise their intellectual bar that serves as a foundation for continued learning (Kolb, 2014). At this point, my bar has been raised to a level that no longer buys into the notion that our systems of governance have humanities' best interests in mind.

As a society, we must reckon with the notion that the systems that got us to our peak civilization, and peak crisis, have proven it won't be the system that provides solutions. We have the capacity for real, meaningful change yet perpetuation of stories that only serve the interests of few redirects human potential toward colonial measures of progress (\$\$) and fuels interpersonal strife while cultural harmony is stifled in the name of capital gains. I no longer see an avenue through which systemic action has any promise of meaningful societal change, unless a radical paradigm shift can occur. Rhetoric that touts solutions as just around the corner is but pander to appease our diminished sense of self-reliance in lieu of a corporate dependency which lives on empty promises and short memories. My emerging worldview takes global agency out of the hands of institutions and puts it in the hands of empowered community. Institutions can no longer be trusted to look out for public good, as the public good in the eyes of leaders (elite) does not reflect what the public good looks like for common people. You need but one season of

growing your own food to realize that the capacity to build a more beautiful world lies within ourselves.

A spiritual and cultural context is missing from our dominant models of agriculture and education in America. When we don't view the land's, or our neighbor's well-being as an extension of our own well-being, we arrive where we find ourselves today. No optimization of yield, X amount of C sequestration, or precision application of inputs will deliver us from these crises if we only address symptoms, not the root of the problem. The root of the solution lies within our capacity to see the natural world, and our fellow humans, as an extension of ourselves. To me, to be educated is to wake up to the interconnected nature of everything, not only as it relates to our learning process, (think active learning, ELT, gestalt psychology, the relational and contextual nature of cognition and learning), but also as it relates to our role in society, to our responsibility to each other to find solutions through connection, compassion, kindness, and empathy.

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