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Cultivating Pedagogy for Transformative Learning: A Decade of Undergraduate Agroecology Education

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Existing scholarship on agroecology and food systems education within U.S. colleges and universities has focused primarily on preparing students to be professionals working in agrifood systems. Developing students' skills and competencies, though vitally important, may not suffice for supporting transformative learning. Transformative learning shifts students' perceptions and awareness and informs future actions, constituting a potential avenue for leveraging education to support transformations toward more socially just and ecologically viable agrifood systems. It is unclear, however, what pedagogies and educational practices enable transformative learning. This paper explores the integration of multiple pedagogical innovations within an advanced agroecology course taught at the University of Vermont. Over a decade, the teaching team has made iterative adjustments to course content and pedagogies with the goal of catalyzing action toward transforming agrifood systems. In this paper, we evaluate our pedagogical approach, asking: (1) How well do course content and pedagogy align with our definition of transformative agroecology as transdisciplinary, participatory, action-oriented, and political? (2) How well does our approach enable transformative agroecological learning, and how is that identified? We present our course evaluation as a case study comprising qualitative analyses of course syllabi, student comments on University-administered course evaluations, and most significant change (MSC) reflections. MSC reflections proved to be a valuable method for identifying and assessing transformative learning. Through a curricular review, we found that substantial changes to course content and evaluative assignments between 2010 and 2020 align with a transformative approach to agroecology. This is validated in students' MSC reflections, which provide evidence of transformative learning. In sharing evaluative results, processes, and insights, we aim to contribute to a broader movement of

scholar educators committed to iteratively and collaboratively developing transformative pedagogies within agroecology and sustainable food system education. We contend that reflexive practice among educators is necessary to leverage education for transforming agrifood systems.

Keywords: agroecology, transformative learning, pedagogy, sustainable food systems education, most significant change, critical food systems education

INTRODUCTION

Courses and degree programs related to sustainable agriculture and food systems are becoming increasingly common throughout North America (Parr et al., 2007; Galt et al., 2012; Jordan et al., 2014; David and Bell, 2018). The rising popularity of sustainable agriculture and food systems education (SFSE) is in part a response to the complex and interwoven social-ecological problems created by industrial agrifood systems (Meek and Tarlau, 2016). Agroecology programs are a popular subset within the diverse courses and degree programs that comprise SFSE (Fernandez et al., 2013; Runck et al., 2015; David and Bell, 2018).

Agroecology is commonly understood to have three dimensions: scientific inquiry, on-farm practices, and social movements (Wezel et al., 2009). Many scholars, practitioners, and activists now emphasize explicitly transformative agroecology that attends to issues of power, agency, equity, and ecological renewal (Anderson and Anderson, 2020). We define transformative agroecology as a transdisciplinary, participatory, action-oriented, and political approach to working toward socially just and ecologically sound agrifood systems. This integrates previous work by Méndez et al. (2013) and González De Molina (2013) on the systems and structures that shape relationships, knowledge, and power within agrifood systems. As in participatory action research processes (Méndez et al., 2017), reflexive practice is necessary to grapple both individually and collectively with the complexity of a transformative approach to agroecology. Reflexive practice allows producers, consumers, researchers, activists, students, and educators to continually and critically assess the impacts of positionality on transformative endeavors.

Transformative agroecology requires distinct approaches to teaching and learning (Anderson and Anderson, 2020). Pedagogical approaches within agroecology education have important implications for which types of knowledge are valued. This, in turn, has important implications for transformation and transition processes (Anderson et al., 2019b). Anderson and Anderson (2020) highlight recent work exploring pedagogy to support transformative agroecology learning, but none of the cited work explores higher education in the U.S. To date, existing scholarship on agroecology pedagogy within U.S. colleges and universities has focused primarily on cultivating students to be future professionals working in agrifood systems (e.g., Runck et al., 2015). Developing students' skills and competencies, though vitally important, may not suffice for supporting transformative learning.

The concept and theory of transformative learning was originally introduced by Mezirow (1978) and Mezirow (1991). Transformative learning entails a shift in a student's frame of reference. Drawing on social constructivist theory, Mezirow's theory of transformative learning suggests that meaning is constructed through experience and reflection (Probst et al., 2019). As a result, transformative learning aligns with experiential approaches to education (Cranton, 1994). Designing learning opportunities that support students in reflecting on their own positionality within food systems, and then facilitating engagement with selected components of their own local food system serve as mechanisms for leveraging higher education to transform agrifood systems. Although scholar-educators exploring agroecology and SFS education cite Mezirow's theory of transformative education (e.g., Galt et al., 2013b; Migliorini and Lieblein, 2016), to date there has been limited explicit consideration of specific pedagogies for transformative learning as defined above. Questions remain regarding how to both identify and assess transformative learning within agroecology and SFS education. What pedagogies facilitate transformative learning? More broadly, how can agroecology education support broader processes of agroecological transformations in the U.S.?

These questions inspired our evaluation of an advanced undergraduate agroecology course offered at the University of Vermont. Over the past decade, course instructors (incl. Méndez, Izzo, Faulkner, Caswell, Horner, and Kinnebrew) have made iterative adjustments to the course in response to emerging research on effective pedagogy for sustainability and critical food systems education. This includes integrating critical reflection, student leadership, and teamwork with several high-impact educational practices (Kuh, 2008) such as experiential- and service-learning and student participation in a long-term participatory action research (PAR) project. Changes to course pedagogy and content have been intentionally cultivated to catalyze action toward transforming agrifood systems.

In this article, we employ case study methods to critically assess this iterative approach to transformative agroecology education within a U.S. institution of higher education. To gain a holistic understanding of how evolving course pedagogy contributes to the broader goals of transformative agroecology, we used the following questions to guide our evaluation: How well do course content and pedagogy align with our definition of transformative agroecology as transdisciplinary, participatory, action-oriented, and political?; and, to what extent does our approach enable transformative agroecological learning, and how is that identified? We also explore an innovative evaluative method to identify and assess transformative learning. Our

analysis indicates that experiential learning on farms, peer-to-peer learning, teamwork, and reflection all contributed to transformative learning experiences for students.

Reflexive practice amongst scholar-educators, as well as critical and iterative course evaluation, are necessary to align pedagogy with transformative agroecology. This article aims to contribute to the ongoing work of exploring the complex connections among pedagogy, transformative student learning, and collective struggles to realize viable and equitable agrifood systems.

OVERVIEW OF AGROECOLOGY AND SUSTAINABLE FOOD SYSTEMS EDUCATION

There are few scholarly articles exploring formal agroecology education and effective pedagogy in the U.S. context. By contrast, there is a robust body of scholarship on SFSE and attendant pedagogies, which provides valuable commentary on extant efforts to design effective courses and degree programs. We briefly review this scholarship with an eye toward identifying the goals of SFSE, the pedagogical approaches employed to achieve those goals, and the methods for evaluating pedagogical efficacy. We then compare the goals, pedagogies, and evaluative methods of SFSE with the smaller body of work on formal U.S. agroecology education. Finally, we identify knowledge gaps related to pedagogy for transformative agroecology learning; this provides the context within which we situate our course evaluation.

Recent SFSE scholarship has focused primarily on identifying key pedagogies for cultivating students' professional capacity to address "wicked problems" within food systems (e.g., Jordan et al., 2005; Galt et al., 2012; Ebel et al., 2020; Francis et al., 2020). Trends within this scholarship are synthesized by Valley et al. (2018), who propose a signature pedagogy for SFSE (SFSESP). They identify four major pedagogical themes comprising a SFSESP: systems thinking; multi-, inter-, and trans-disciplinarity; experiential learning; and participation in collective action projects. Valley et al. (2018) propose that a signature pedagogy framework can be used to identify approaches for educating future professionals working within agrifood systems.

The professional framing of Valley et al.'s (2018) SFSESP builds on earlier work emphasizing competency development within SFSE. Galt et al. (2013a) proposed a focal shift from content to student skill development, arguing this will support a future generation of professionals capable of tackling "wicked problems." Within this competency framework, values-based pedagogy (Galt et al., 2012) and critical pedagogy are presented as building blocks in the development of a skilled workforce. The concept of educating for professional skills and competencies remains central in recent SFSE scholarship (Ebel et al., 2020; Valley et al., 2020) as well as broader calls for a sustainable food systems workforce (Carlisle et al., 2019).

While the signature pedagogy and competency frameworks highlighted above focus on cultivating students' professional capacity, Meek and Tarlau's (2016) framework for critical food systems education (CFSE) offers a more political approach focused on developing students' transgressive subjectivities. They argue that rather than focusing exclusively on students' understanding of food systems complexity, education and innovative pedagogies should be leveraged to support agrifood systems transformation. In proposing their CFSE framework, Meek and Tarlau (2016) contend that there is a tension between these two educational paradigms. Rather than being mutually exclusive, however, Meek and Tarlau advocate for complementarity between professional and transformational approaches to food systems education. They propose integrating innovative pedagogies from SFSE with critical insights and pedagogies rooted in grassroots movements and popular education. Despite the potential of this integrated approach to food systems education, the CFSE framework remains underutilized within scholarship proposing and analyzing food systems pedagogy in the U.S. (Classens et al., 2021 are a notable exception). More frequent use of signature pedagogy and competency frameworks within this body of work is further indication of an educational approach oriented toward professionalization rather than transformation.

The limited scholarship on agroecology education also focuses on skills and competencies. In an early review of an undergraduate agroecology course, Jordan et al. (2005) identify service-learning as a valuable pedagogical tool for applying systems thinking. The service component of the course was framed as an attempt to cultivate a sense of civic professionalism, defined by the authors as "professionals who orient work to projects of civic innovation and renewal." Similarly, Runck et al. (2015) propose an extended classroom framework integrating systems action education with adventure learning to develop students' capacity to tackle "wicked problems." Within agroecology education, capacity building is defined as "the process used in education to improve students' abilities to work effectively with challenges they will face in agriculture and food systems development and research programs" (Francis et al., 2012). Capacity building aligns with the competency frameworks guiding SFSE and suggests a focus on agroecology education as an avenue for professionalization.

Of the articles we reviewed that examine formal agroecology education in the U.S., only one aligned with a more transformative approach to agroecology education. Code (2017) explores research methods and experiences driving the design, development, and delivery of innovative agroecology pedagogy. In their analysis, they argue that epistemological innovations must be included as a component of pedagogical innovations within agroecology education. The author defines epistemological innovations as ways of knowing beyond Western scientific inquiry, disciplinary education, and systems thinking. Instead, Code (2017) advocates for pedagogical approaches that emphasize the relational, contextual, and experiential foundations of knowledge. They contend that attending to epistemological innovations within agroecology education is necessary for transformation toward more holistic ways of knowing that encompass the full complexity of agroecosystems. Expanding the types of knowledge included enables agroecology education to contribute to what the author terms "paradigmatic change," in addition to cultivating skillful future professionals.

This aligns with Meek and Tarlau's (2016) proposal for complementarity between professional and transformational approaches to food systems education. Code (2017) does not explicitly espouse transformative agroecology or transformative learning, though their insights on the interconnections between epistemology and pedagogy imply a holistic and equity-oriented approach to agroecology education that aligns with transformative agroecology.

In exploring the development of pedagogical innovations within agroecology education, Code (2017) reviews a subset of the scholarship focused on agroecology pedagogy within the U.S. and Europe. Their review demonstrates the dominance of the Norwegian graduate program within the agroecology pedagogy literature. Although scholar-educators involved in the Norwegian Master's program have developed and shared formative insights on agroecology education, their work emerges from a unique context. As a result, it may not translate fully to undergraduate courses in North America. This suggests the need for further research on pedagogical innovations and their efficacy in U.S. institutions of higher education.

Classens et al. (2021) note that scholarship has largely overlooked how the pedagogical approaches and efficacy of SFSE are mediated by the institutional conditions within which teaching and learning occur. Specifically, Classens et al. (2021) review how the neoliberalization of higher education has contributed to a focus on "education as a tool for the reproduction of a globally competitive workforce." The authors argue that CFSE must attend to the diverse institutional conditions of colleges and universities in order to contribute to agrifood systems transformation.

Based on our review, it is evident that there are many shared goals and pedagogical approaches across SFSE and agroecology education. With some notable exceptions (e.g, Galt et al., 2013b; Code, 2017; Classens et al., 2021), much of the scholarship exploring food systems and agroecology education emphasizes education as a tool for professionalization. This common goal translates into common pedagogical practices. Experiential education, action education, inter- or trans-disciplinarity, and systems thinking are emphasized across the literatures. In addition to pedagogical overlap, there is a commonly identified need for more dynamic evaluative methods and long-term research on student learning experiences to assess the efficacy of innovative pedagogies within agroecology and SFS education (Galt et al., 2012; Code, 2017; Valley et al., 2018).

The need for evaluations of pedagogical efficacy must be considered alongside the specific and possibly competing goals of agroecology and SFS education (Meek and Tarlau, 2016). Courses and programs designed to train future professionals may have distinct pedagogies when compared to courses or programs focused on transformative learning. Where goals and pedagogical approach differ, so too will methods for evaluating pedagogical efficacy. There is a need for scholarship exploring how professional and transformative approaches to agroecology and SFS education can be integrated, and how to evaluate the efficacy of this integrated approach. To date, however, there has been relatively little attention paid to transformative learning in agroecology or SFSE scholarship. Assessments of effective pedagogies for transformative learning constitutes a vital next step for agroecology and SFS education.

We situate our course evaluation within these gaps in the scholarship on SFS and agroecology education. In evaluating the evolution of our course pedagogy over time, we explore how to align pedagogy with transformative agroecology and introduce a novel evaluative methodology for identifying and assessing transformative learning.

METHODS

Interactions between course design and student learning constitute complex social processes. To attempt to make sense of this complexity, we integrated multiple analytical methods and data sources within our process of course evaluation. Our methods follow a non-experimental, interpretive, and retroactive case study approach. Case studies have previously been useful in course evaluations that seek to explore relationships between student learning and course pedagogy in the context of food systems education (Galt et al., 2013b). The case study method also aligns with the concept of "agroecological lighthouses" (Altieri, 1999), which have been described as examples "from which agroecological principles radiate out" (Nicholls and Altieri, 2018).

We begin with a description of the course, which provides important context for the ensuing analysis and discussion. We then provide an overview of the data sources and analytical methods employed to evaluate various aspects of course design. Our analysis includes two components. First, we conduct a curricular review based on syllabi from the past 10 years. Second, we share results of thematic analysis of student evaluations over the same 10-year period as well as student reflections from the most recent iteration of the course, which took place from September through December 2020.

Case Study Context

The University of Vermont is a Land Grant university located in Burlington, Vermont. The Advanced Agroecology course has been taught in the Plant & Soil Science Department since 2008.

The course is required for undergraduate students studying Agroecology. It is also popular with students in the Food Systems and Environmental Studies programs, who consistently constitute about 50% of the class. The course is usually composed of third- and fourth-year undergraduate students and a few graduate students.

Advanced Agroecology holds twice weekly lectures and a weekly 3-hour lab. There are typically five lab sections, and each section is paired with a local farm. In 2020, however, we worked with three partner farms after one farmer partner retired and another farm was unable to host students during the Covid-19 pandemic. The three farms we partnered with in 2020 include: an urban collective farm focused on annual vegetable production, a peri-urban diversified livestock-vegetable operation, and a working educational farm affiliated with the University.

We use the term "farm teams" in this course to foster the sense that each lab section constitutes its own micro learning community. Over the course of the semester, the farm teams

spend most labs at their partner farm. As of 2018 the Advanced Agroecology course also includes undergraduate agroecology research fellows (UARFs) who function as farm team captains, providing peer leadership. This role requires liaising with farmer partners, coordinating use of shared lab equipment, and organizing peers for on-farm lab activities.

Curricular Review

To explore the extent to which course design aligns with the tenets of transformative agroecology, we conducted a curricular review of the course over a ten-year period. Curricular reviews can identify key pedagogical themes across multiple curricula (Valley et al., 2018). We began by qualitatively identifying course learning objectives, teaching methods, assigned content, and evaluative assignments as presented in course syllabi from 2010 to 2020. This process enabled comparative analysis of how course design and pedagogy have evolved over time. We then employed content analysis to identify focal topics and prominent voices within assigned materials and compared content analyses from 2010 and 2020 to identify changes over time.

The curricular review was guided by the tenets of transformative agroecology. We considered whose voices were represented in assigned materials, where those voices were located, and whether course materials, focal topics, teaching methods, and evaluative assignments aligned with a transdisciplinary, participatory, action-oriented, and political approach to agrifood systems transformation.

Thematic Analysis

To evaluate the efficacy of course pedagogy for transformative learning, we conducted thematic analyses of open-ended student comments in end-of-semester course evaluations as well as student reflective essays submitted at the end of the 2020 course. Prior research indicates that conventional course evaluations are not well suited for assessing student-centered instruction, problem-based learning, and complex learning (Frick et al., 2010). Open-ended evaluative comments do, however, provide insight into students' experience of the course over time. To address the limitations of student evaluations, we integrated a most significant change (MSC) reflection. In the MSC reflections, students responded to a prompt asking them to identify the most significant change in their thinking about agrifood systems during the course. MSC methodology was developed by Dart and Davies (2003) as a holistic, participatory tool for evaluating development projects. Moving beyond evaluation of pre-defined outcome metrics or indicators, MSC techniques allow individuals most impacted by an intervention to share their experiences in a holistic manner. In an educational setting, MSC techniques require critical reflection on the outcomes or changes experienced through participation in a project or course (Choy and Lidstone, 2013). Acton (2019) notes that inclusion of MSC techniques facilitates student self-reflection on their own educational experiences.

All student evaluations and MSC essays were uploaded to *NVivo* 1.4.1 and coded. We used sensitizing concepts related to our research questions to guide the initial analysis (Bowen, 2006). Charmaz (2003) posits that "sensitizing concepts offer ways of seeing, organizing, and understanding experience." Within grounded theory research, sensitizing concepts are used as a foundation for analysis. Initial sensitizing concepts of transformative agroecology and transformative learning guided the first phase of coding for both the student evaluations and the MSC essays.

In developing initial codes, we used a constant-comparative method. This analytical approach entails constantly comparing data during the process(es) of coding (Leech and Onwuegbuzie, 2007). This process also enabled us to identify linkages between data sources. We grouped initial codes of student evaluations and MSC essays to identify major themes relevant to our course evaluation (Creswell, 2013). We identified a unique set of themes for the two data sets, but we compare these themes, along with results from the curricular review, within our discussion. Themes provided a frame for making sense of students' learning and transformation in relationship to course pedagogy.

The final step of our thematic analyses entailed "member checking" our results (Creswell, 2013) with individuals who were students in the course. Sharing findings with individuals who have intimate knowledge of the case being studied is an important method for validating interpretative case study analysis (Yin, 2013). These prior students all served as farm team captains in their role as UARFs. As a result, they carried unique insight into the experiences of their peers. We asked the students if thematic analyses of student evaluations and MSC reflections resonated with both their own experiences and with the informal feedback they received from their farm teams. They validated our analyses and provided critical feedback that helped us better represent the full complexity of student experiences. Confirming our analyses with prior students, integrating multiple data sources, and applying multiple analytical methods enabled a more holistic evaluation of course pedagogy and student learning.

RESULTS

First, we present findings on the curricular review, focusing specifically on the aspects of course pedagogy that have evolved substantially in the past 10 years. After analyzing the evolving curricular context, we present thematic analysis of institutional student evaluations over the same 10-year period. Finally, we turn to the MSC essays to identify themes across students' transformative learning experiences. This section focuses disproportionately on students' 2020 MSC essays. Due to the nature of the prompt, these essays yielded an extremely rich source of data on how course content and design supported transformative learning. Additionally, as the most recent students to have taken the course, this content presents the most relevant means of assessing the efficacy of current pedagogy for supporting transformative learning.

Curricular Review

In our review of syllabi from 2010 to 2020, we identified six aspects of course pedagogy that we deem central to course design and intended student learning. These include course learning objectives, the evolution of a collaborative and transdisciplinary

TABLE 1 | Learning and teaching outcomes (LTOs) as listed in course syllabi.

	2010	2020
LTO 1	Students become familiar with current research and applied concepts and applications within the field of agroecology.	Students become familiar with current research and applied concepts and applications within the field of agroecology.
LTO 2	Through hands-on field and ***laboratory*** exercises in local farming systems, students learn ecological and social research and analytical skills, which are commonly used in agroecology and agrifood systems research.	Through hands-on field exercises in local farming systems, students learn ***practical***, ecological and social research and analytical skills, which are commonly used in agroecology and agrifood systems research.
LTO 3	Students practice working in groups.	Students practice working in groups.
LTO 4	Students practice their critical thinking and communication skills throughout the course by participating in discussions and preparing written and visual material.	Students practice their critical thinking, ***reflection*** and communication skills throughout the course by participating in discussions and preparing written and visual material.

Changes are italicized. Despite substantial changes to course content and pedagogy, there is little substantive change in the learning outcomes guiding the course.

teaching team, the integration of the course with a long-term PAR project, the integration of undergraduate agroecology research fellows (UARFs), assigned content, and student-led discussions (SLDs).

The learning objectives of the course essentially remained unchanged despite the multiple changes implemented in response to both student feedback and emerging research. Between 2010 and 2020, "practical skills" and "reflection skills" were added to course learning objectives (**Table 1**).

The earliest pedagogical shift is the introduction of teaching team members. Initially the course was taught by Professor Méndez. Over time, Méndez incorporated multiple faculty collaborators whose work aligned with the expanding course content and focal topics. The creation of a teaching team co-evolved with the formalization of farmer partners' role in the course *via* integration of a long-term PAR project started in 2017. The PAR process was formalized to integrate on-farm research in a way that was beneficial to both student learners and farmer partners. As a pedagogical tool, PAR leverages student learning to support farmers' management processes. The PAR project also created greater coherence between the service-learning and soil science research components of the course, insofar as initial weeks of service-learning enabled relationship- and trust-building foundations for engagement between farmers and students within the PAR project. Shifting to a PAR approach also required greater reflexive practice among the teaching team as we collectively navigated iterative cycles of service-learning and research. This complemented a growing emphasis on reflexive practice in the curriculum as evidenced by reflective essay assignments and in-class reflective exercises (**Figure 1**). Through this work instructors sought to engage students in thinking about their previous and current experiences and their connections to food, the food system, and the agroecological content of the course.

The integration of a long-term PAR project with the course necessitated additional support for managing the considerable logistical challenges of coordinating not only five lab sections, but also five partner farms. To address this challenge, instructors incorporated UARFs to liaise with farmer partners and provide peer leadership within farm teams. The integration of UARFs was also designed to align with course learning objectives and key pedagogies that emphasize peer-to-peer learning.

We conducted content analysis on all assigned materials and evaluative assignments. We found a marked shift in both the agroecological topics and sources highlighted within course materials from 2010 to 2020 (**Figure 2**). This finding aligned with qualitative coding of the syllabus, which revealed a transition from a predominant emphasis on agroecological science and practices toward greater inclusion of food sovereignty, social movements, and PAR.

We also identified substantial changes in the evaluative assignments required of students over the past decade. Although SLDs occupied one out of two weekly lectures in 2010, this decreased to five SLDs over the course of the semester in 2020. SLDs provided a chance for students to assume the role of teacher and to learn from peers, disrupting the traditional student-teacher hierarchy and top-down model of knowledge transfer (Anderson and McLachlan, 2016). The semester-long research paper was substituted for a shorter assignment with greater creative license granted to students, who were able to choose between a blog post and a research brief. Providing choice within both course materials and evaluative assignments pushed students to reflect on what types of learning suit their learning goals and preferences. Student choice regarding assignments also evidences a more participatory pedagogy designed to facilitate students' sense of agency within their education. The introduction of reflective essays also demonstrates a transdisciplinary pedagogy that seeks to integrate multiple types of knowledge as well as students' past experiences, beliefs, and values within course learning.

Student Evaluations

Across 10 years of formal student evaluations administered through the University, we identified three major themes: experiential learning, peer-to-peer learning, and critiques of course design.

Since 2010, student evaluations have clearly demonstrated widespread appreciation for on-farm learning. Students' on-farm experiences evolved over the years from a service-learning and soil sampling lab hybrid to a combination of service learning and PAR. Student evaluations consistently emphasize the power of hands-on learning from farmers, with a distinct emphasis on the service-learning portion of the course. Despite the integration of a long-term PAR project, students do not explicitly mention participating in the PAR project as a valuable component of experiential learning.

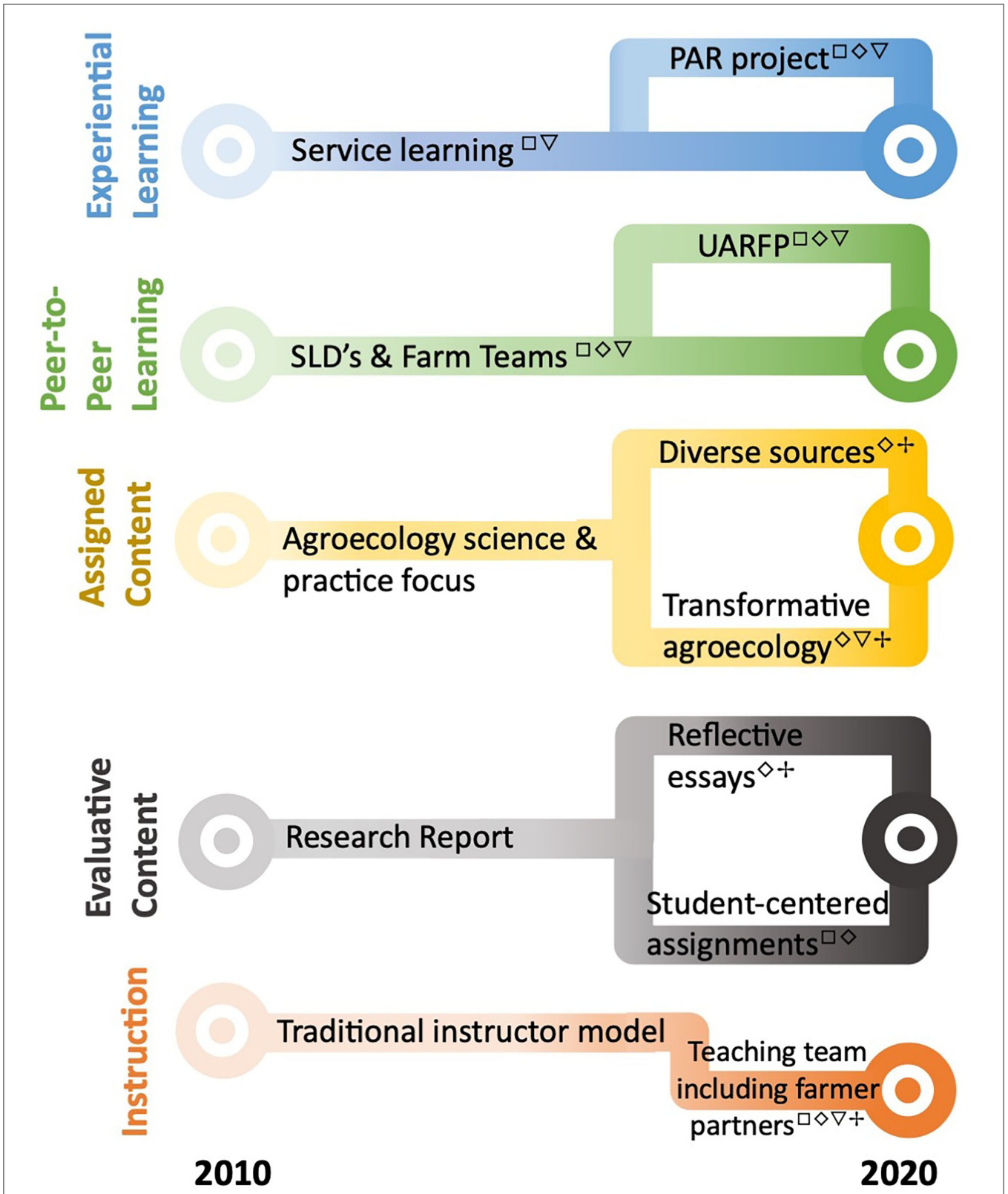

FIGURE 1 | This highlights the evolution of course pedagogy from 2010 to 2020. Major course components are grouped into pedagogical elements to provide a sense for how all elements of course pedagogy have co-evolved. The color saturation gradient represents the intentional shift over time toward pedagogies more aligned with a transformative approach to agroecology. Superscripts indicate the tenets of transformative agroecology supported by each pedagogical innovation: □—Participatory, ◇—Transdisciplinary, ▽—Action-oriented, +—Political.

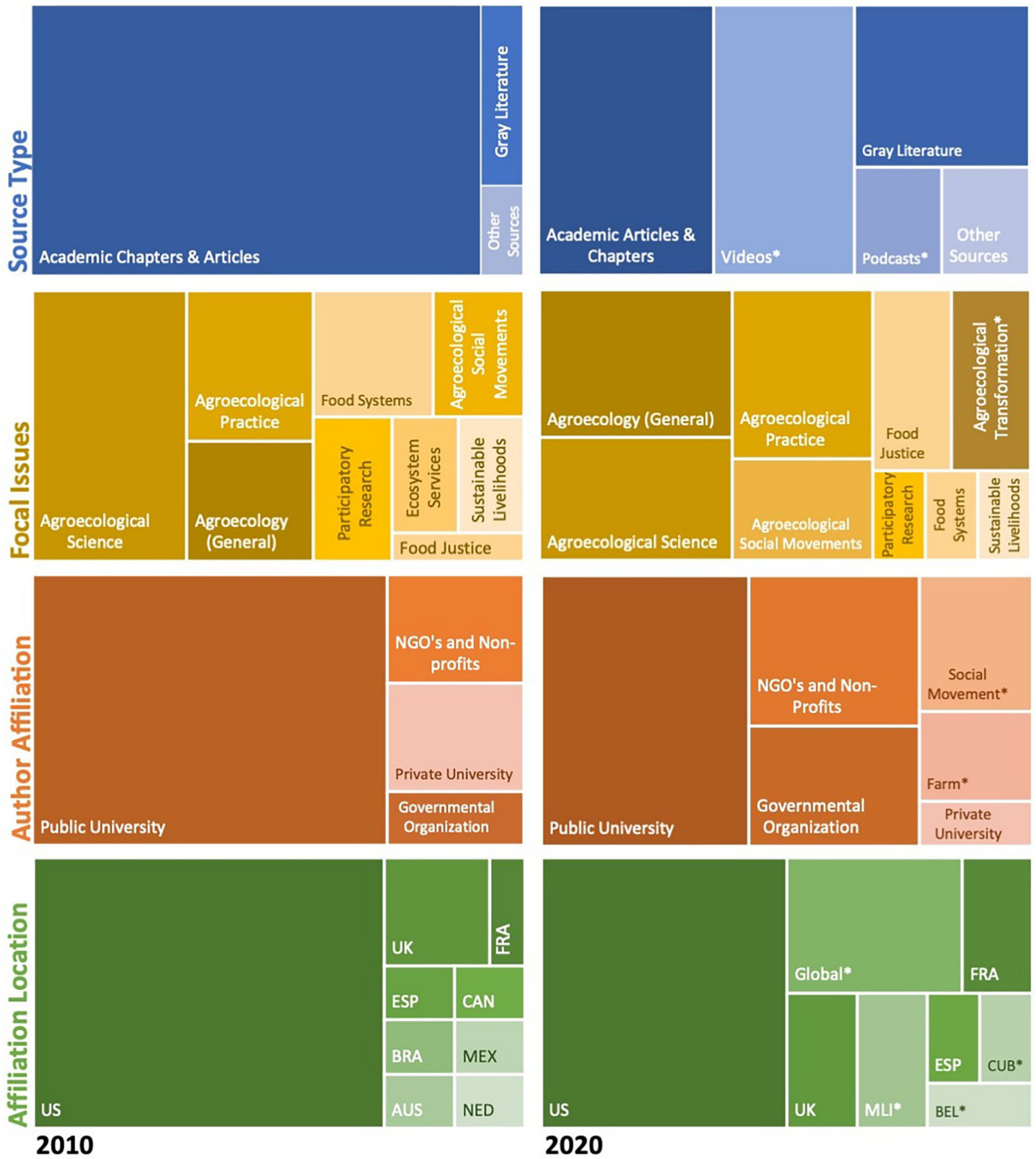

FIGURE 2 | Comparative content analysis of assigned course materials in 2010 and 2020. The size of sub-rectangles represents the quantity of sources of that type in the respective year's syllabus. Gray Literature includes policy briefs, research briefs, and content from popular books and news print sources. "Other sources" includes movement manifestos and encyclopedia entries. *New in the 2020 syllabus.

In addition to hands-on learning on farms, students emphasized the value of peer-to-peer learning. Student evaluations indicate widespread appreciation for student-led discussions. Students reported high levels of course engagement when preparing SLDs with their farm teams and learning from their peers when other groups led discussions. Although course

redesigns decreased the number of student-led discussions over the years, reported appreciation of SLDs increased. The year in which students most commonly and forcefully emphasized the value of SLDs was the first year of the UARF program. As part of their fellowship, UARFs took a lead role in coordinating SLDs, which may explain the particularly forceful emphasis on SLDs as an important site of peer-to-peer learning.

Despite appreciation of experiential and horizontal learning, student evaluations presented substantial critiques of course design. Many student critiques were constructive, such as a 2020 student's suggestion to further highlight and honor indigenous knowledge and spiritual ways of knowing. More frequently, students identified frustrations and deficits with course content. Three consistent critiques appeared across all 10 years. First, students expressed a desire for more emphasis on local examples of agroecology and were frustrated by the emphasis on Latin American case studies in lectures. Second, students cited frustration with the theoretical or abstract content presented in lectures. Specifically, students expressed a desire for less emphasis on PAR, social movements, and the political aspects of agroecology. This ties into students' desire for more practical "how-to" content, which constitutes the third major critique that appeared across the years. Students' interest in hands-on learning over distant case studies lends credence to a central argument of transformative agroecology: that theory and practice mutually complement one other when theory is built out of practical dilemmas. It is not necessarily a less political agroecology that students seek, but rather one built out of their experiences and the cognitive-emotive complex. The fact that, as students in lab, there is no reason to "struggle" for access to seeds, water, or land can make the more overtly political aspects of the course less tangible. These critiques also imply a disconnect between lectures and lab; students struggle to understand their on-farm experiences as exposure to local agroecological practices constrained and shaped by social, political, and environmental forces.

Despite offering feedback on student satisfaction with key components of course design, survey comments did not provide indications of transformative learning. Responses focused on what students enjoyed, and more often on what was lacking or frustrating regarding course design. Survey responses can inform instructors' iterative redesign of course materials and pedagogies but offer little insight into how these changes influence student learning outcomes.

MSC Reflections

Our analysis of student MSC essays revealed five categories of transformative learning during the most recent 2020 semester. The transformative learning categories include student empowerment, relationship-building, learning related to social justice, systems thinking, and transdisciplinary learning. These categories capture forceful themes within the students' reflective essays on their most significant learning during the semester. These categories also include references from all 25 of the essays considered.

Due to the nature of the writing prompt, nearly all students identified one or more areas of transformative learning during their engagement with the Advanced Agroecology course. Although in certain instances students self-identified their learning as transformative, it was more common that interpretation was required. We interpreted instances in which students expressed shifts in perspective and consciousness or awareness as indicative of transformative learning.

Empowerment

Students' perceptions of their roles and responsibilities within agrifood systems changed in multiples ways as a result of taking this course. We identified three sub-themes that capture students' sense of empowerment in contributing to agroecological transformations: shifting consumer identities, increased self-efficacy, and future visioning.

Multiple students viewed their learning through the lens of consumer identity. These students reported developing a deeper awareness of their responsibilities as consumers alongside increased capacity to make ethical consumer choices. For example, one student wrote, "I have gained confidence as a consumer because I feel I am more aware of the food system I am a part of, which can help me make more informed decisions." Other students echoed this sentiment, confirming that their learning in the course enabled them to become more "sustainable" consumers. These statements indicate a degree of personal transformation as students become aware of their embeddedness within agrifood systems.

Other students, however, demonstrated what Anderson et al. (2019b) term "more-than-consumer" consciousness, which implies awareness of the political implications of consumers' decisions and role(s) within agrifood systems. For some students, this shift in consciousness was deeply personal, as with one student who wrote, "I know that what I have learned in this class will be the beginning of my process of reconnecting with the food that I eat." For others, their more-than-consumer consciousness extended outward:

> By being able to critically address the issues of food sovereignty within our food systems, as well as being able to recognize the role of agroecology in politics and as a social movement, I truly became aware of my duty as a student to speak up and fight against the social, environmental, and political injustices of our time.

This student experienced a shift in their understanding of the "duty" they have to engage with agrifood systems beyond the role of consumer.

The perception of personal responsibility and capacity to participate in agrifood systems as more than a consumer aligns with an increased sense of self-efficacy evident in many student essays. One student reported that through learning about the political dimensions and implications of agroecology, they perceived that they could have an impact in agroecological movements. This student went on to share a new commitment to participating in local politics. Others similarly communicated intentions to mobilize their learning from the course to participate in social movements related to agriculture, food, and racial justice more broadly.

For other students, increased self-efficacy was framed in a more internal way. One student reflected,

"As the semester draws to a close, I realize that the experiences and lessons I learned through [Advanced Agroecology] have allowed me to recognize my strengths as a student and the possibilities for expanding this role well beyond just an academic setting." This reflected a transformation in the student's perception of themself and their capacities. Another student similarly reflected on the leadership role they assumed in their group, noting "I really have not identified myself as a leader in much of my life. However, working on the farm made me question why I don't see myself fitting in those shoes." Through their experience working with peers on their partner farm, this student began to perceive their leadership capacity and question why they had not previously identified as a leader.

Finally, multiple students communicated an intention to utilize the skills and knowledge gained through the course in their future endeavors. For some students, the experience of service learning on partner farms affirmed or strengthened a preexisting desire to work in agriculture. For example, one student reflected, "I feel grounded in the fact that what I've learned from this class, combined with everything I've learned outside of it, will help me do the work I always knew I was meant to do, the work of fighting for a just world through… food." Other students, however, directly connected their learning in the course to changes in their perceived capacity to integrate agroecology into their professional futures. One student noted that "Advanced Agroecology has enlightened me with future career pathways and skills that I didn't realize that I was capable of." This demonstrates how course content can transform students' plans and perceptions of the possible.

Social Justice Learning

Nearly all (20 out of 25) student essays connected their learning in the course to an enhanced awareness of social justice issues. Within this category, we identified three subthemes that captured the range of students' transformative learning related to social justice: systemic racism within food systems, collective action, and critical consciousness. Considered together, student reflections indicated that when course pedagogy pushes students to consider issues of justice and equity, it enables students to connect the ecological and social-political dimensions of agroecology.

Several students explicitly named systemic racism as one of the social justice issues entangled with agrifood systems. Many students related their learning in the course to a heightened awareness of racial inequities, exploitation, and oppression. As one student explained,

> Racial justice goes right along with food justice and agroecology, because our food system is racialized. To practice agroecology should also mean to fight for racial and social justice of all kinds, because they all intersect–we cannot solve one of these issues without solving the other.

In communicating their learning, awareness, and engagement with issues related to racial justice, students demonstrate the application of Freirean praxis, which Meek and Tarlau (2016) define as a dialectic between learning and taking action "to change the inequitable social, economic, political, and agricultural systems that shape our lives". Indeed, several students shared the ways in which their learning in the course motivated them to engage directly with social justice projects and movements. One student connected their participation in Black Lives Matter protests and political engagement with their new capacity to "critically [apply] what [they] learned in this course to recognize the importance of valuing the ecological knowledge and practices of various cultures, knowledge systems, and disciplines."

In learning about the social-political dimensions of agroecology, many students reported a transformed understanding of the role of social movements, grassroots organizing, and collective action in realizing sustainable agrifood systems. For instance, one student reflected that "after gaining a better understanding of agroecology as a movement, I would suggest the movement is at least equally as important as practices and principles, if not more important." Another student reflected on their "newfound recognition that farmers can be active agents of transformative change in a food system, rather than solely responsive to and restricted by market forces and policies." These statements demonstrate enhanced awareness of the power of collective action and grassroots organizing for change within agrifood systems.

Some students framed their perception of social movements in more deeply personal terms, such as one student who stated that their new understanding "of how social movements function and why they are necessary in agroecology… changed the way I think about the world and my role in it." Another student went a step further in reflecting on how their learning transformed their perception of the role of collective action in creating viable agrifood systems:

> I've realized that maybe focusing on my own situation and my family's farm is not going to achieve much, and that I would probably fail by myself. The interconnectedness and prevalence of agriculture across our societies forces any transition in food systems to be undertaken by whole communities that can support themselves and not by individuals fighting their own "good fight."

These quotes demonstrate the powerful linkages across social justice learning, self-efficacy, and systems thinking as students' awareness of the social-political dimensions of agrifood systems transforms their perceptions of their roles and responsibilities in working toward sustainability.

Finally, many students demonstrated development of a critical consciousness. General statements regarding the impacts of globalization and neoliberal trade agreements on peasant and rural livelihoods indicated critical consciousness of the intersection of agrifood systems and international political economy. Many students also explicitly reflected on their increased awareness of the inequities stemming from capitalism and industrial agriculture.

> If anything has changed this semester, it has been my thinking around capitalism. It has never been so apparent to me the ways in which it hurts so many members of our society. While

> agroecology can be a solution within this system, I don't think it can reach its full extent with farming corporations ruling our food system.

This example demonstrates that not only did students develop critical consciousness through course pedagogy, but they were also then able to apply that critical consciousness to their understanding of agroecological transformations.

As with earlier sub-themes, some students developed their critical consciousness in more personal terms. For example, one student reflected that how gender operates within agrifood systems had become a topic of increasing interest and importance. It is interesting to note, however, that despite a vast majority of female students, the intersection of gender and equity within agrifood systems was not a prominent theme. More students focused on critical analysis of economic and racial inequities. In reflecting on their social justice learning, students integrated multiple aspects of course pedagogy, from their discussions with farmer partners, to lectures, student-led discussions, and assigned content related to food sovereignty and food justice.

Systems Thinking

Critical consciousness often develops alongside systems thinking capacity. As students become more aware of the systems and structures that (re)produce inequities and injustices, they are better able to consider the full social-ecological complexity of agrifood systems. Systems thinking is evidenced by students grappling with complexity, identifying the interdependence of social and ecological dimensions of sustainability, and perceiving their embeddedness within agrifood systems.

For many students, increased awareness of and engagement with social justice and food sovereignty movements led to shifting perception of what constitutes sustainable agriculture. One student reflected,

> What a grower does day-to-day, I thought, was the backbone of agroecology. But after discussing the Declaration of Nyéléni, I realized that to study agroecology as a whole is not just to study agriculture. It is a whole philosophy on global food systems made to support growers' livelihoods, food sovereignty, and living in harmony with nature.

While some students came to perceive the social-ecological interweaving of agroecology through assigned material and discussions, other students did so through their on-farm experiences. For example, one student reflected, "I had never considered that a farm could have much of an impact beyond the soil they grow on and the surrounding ecosystem." After spending time on their partner farm during labs, this student came to see that farms play a vital role in supporting communities and preserving culture. Other students noted that both readings and farmer conversations around livelihoods and PAR expanded their awareness of the social components of sustainable agrifood systems.

The process of grappling with the full complexity of agrifood systems was not always a comfortable one for students. Many students reflected on ways in which they perceived their prior education to be lacking. For example, one student noted that their previous courses "oversimplified the life of a farmer" in ways that promoted an incomplete understanding of agrifood systems. In reflecting on their learning in the course, another student wondered, "How can agroecology work within the system to create change? How can two sets of conflicting values, agroecological principles and agricultural production that exists within a capitalist society, manage to create some change within the system?" Asking complex questions can lead to frustration when no simple answers are possible, but the process of considering such questions is indicative of complex systems thinking and is vital for agroecological transformation.

Relationship Building

While systems thinking often arose in conjunction with learning about social movements and justice, systems thinking also developed alongside student perceptions of the importance of relationships in agroecology. Interactions with peers, the teaching team, farmers, and the farms fostered new relational awareness. As one student put it, "It was the people and the conversations that have helped me to grow throughout the course of the semester." In exploring student learning tied to relationship building, we identified three sub-themes: appreciation for cooperative agriculture, appreciation for community, and relational processes of horizontal learning.

Multiple students reported a change in their perception of farming as a communal or community-building endeavor. One student reflected, "I always perceived farmers as being more profit oriented and worrying about the market prices and whatnot. However, [our partner farmers] revealed that their priorities lie in their community's needs." This is representative of students' shifting awareness of the ways in which farms play important roles in supporting and building communities.

Students also reflected on the ways in which cooperative approaches to agriculture benefited farmers. On one farm a student noted, "in the same way my lab group aided me this semester, it is [the farm's] collaboration of perspectives, thoughts, and ideas that helps them continuously improve." On another farm, a student reflected that over the course of the semester she became aware that farming "is something that I truly believe one cannot do on their own… farming is also an experience that I believe should be shared between people and allows for unique and strong connections." Despite differing partner farm business models, students from all farm teams reflected on the community-wide relevance of agroecology.

Students also shifted how they personally related to the concept of community within the context of agroecology. One student reflected "I really loved working with people who were just as passionate about learning and growing as I was, and it helped us not only grow food well, but also foster community well, something that felt especially important during this time of Coronavirus." Interacting with peers and farmers during lab periods enabled students to engage in learning about agroecology in the context of building relationships. This experience fed back into transformative learning, as students were able to

identify the power of relationships for realizing agroecological transformations. For example, a student reflected that,

> Through my involvement in our class, my farm team, and Catamount Farms I have found belonging and community in a way that lacked in my previous experiences. Fundamentally, finding a sense of belonging through active involvement is a principle that I will use going forward as I look to influence change and build relationships in my future.

Service learning on farms enabled students to build relationships with both peers and farmers. These relationships, rooted in place, enhanced student learning regarding the relational nature of agroecology and transformative processes.

One way that relationship-building enhanced student learning was by enabling peer-to-peer or horizontal learning. Multiple students noted the power of learning with and from their peers. In reflecting on their learning experience within their lab group, one student shared appreciation for the diverse backgrounds of their peers and the "excellent perspectives, thoughts, and ideas" they added to the on-farm learning portion of the class. For some, these experiences led them to shift their understanding of who can be an educator and how learning happens. One student noted, "So much valuable knowledge is shared and considered when done through horizontal learning that my past classes failed to teach me." Experiences cultivating and learning in community settings, in which peers and farmers became important sources of knowledge, expanded students' notions of the purpose and processes of education and transformative learning.

Transdisciplinary Learning

This was the most forceful category we identified in the students' reflective essays. We identified transdisciplinary learning through both explicit and implicit language related to critical learning that transgressed traditional boundaries that define higher education courses. Through this process, we identified three sub-themes of transdisciplinary learning: expanding perceptions of education, epistemological plurality, and critical reflection. Across these sub-themes, students emphasized the power of experiential learning and the ways in which course pedagogy enabled learning beyond academic disciplines.

The experiential education students received on their partner farms during weekly lab periods provided the primary pathway to transformative transdisciplinary learning. For many, this experience contributed to an expanded sense of the purpose and sites of agroecological learning. After a semester of on-farm learning, one student reflected, "I changed my attitude toward education. No longer was I there to check off a box so I could get somewhere I actually wanted to be. I was there to be present and observe what was happening around me." While for this student, the process of expanding their conceptualization of education entailed intimate connection with place, for others the process was more fraught. One student recalled,

> Heading into this agroecology class, I was so excited to learn more interesting facts—what plants are best intercropped with one another? How do growers control pests ecologically? Instead, I was met with nebulous theory, philosophy, and paradigm, which actively worked to undo my thorough grasp of the world.

Transdisciplinary learning may require students to unlearn in order to learn, and this can be a disorienting and uncomfortable process.

Transdisciplinary learning requires students to reflectively make sense of complex experiences and diverse knowledges, and to integrate this learning with past experiences and personal values or beliefs. Students demonstrated critical reflection in both explicit and implicit ways. For example, one student continually related course content back to where they grew up, noting that prior to the course, "[their] own reflections have always been focused in looking at alternatives to corn and soybean that can be just as profitable or just as pragmatic to implement." In reflecting on course content, however, they shifted their perception of agrifood systems in their home country. Another student similarly shared, "several of the things we studied I connected with my previous experiences, creating both nuance and a deeper knowledge."

Reflecting on their experiences and learning expanded students' perception of valid knowledge beyond the Western, academic delimitation. Course pedagogy was designed to support epistemological plurality, with students learning from farmers and being exposed to diverse perspectives and knowledge sources in assigned materials. Student reflections demonstrated how the diversity of course content and pedagogies interacted to align the course with agroecological principles of epistemic plurality: "I was intrigued by this term [*diálogo de saberes*] when I first heard it in

Ernesto's lecture, but it was not fully illustrated for me until I witnessed [our partner farm] carrying it out." In this example, a student understands the concept of *diálogo de saberes* ("dialogue of knowledges") by contextualizing it within their on-farm experiences. At a different farm, a student similarly reflected,

> The class was an illuminating example of how different ways of knowing can interact and collaborate. For example, while we conducted soil tests with standardized instruments, [our partner farmer] explained that [they] wear sandals in order to feel the textures, humidity, the slope and other physical factors of the soil.

Through the integration of lectures, discussions, reflections, soil sampling, PAR, and experiential learning on farms, students are exposed to multiple ways of doing, learning, and knowing agroecology.

DISCUSSION

Our evaluation reveals that the Advanced Agroecology course has evolved toward a more inclusive pedagogical approach that aligns with our definition of transformative agroecology and effectively facilitates transformational learning (**Figure 1**).

Lessons Learned From Ongoing Curricular Review

Our analysis of course content demonstrated the importance of ongoing review and a willingness to update pedagogical techniques over time. In our course, changes to course content, and assignments promoted greater student agency. This aligns with broader efforts to cultivate more inclusive and transdisciplinary pedagogies that do not maintain a dominant emphasis on scholarly research and Western, scientific knowledge (Quaye and Harper, 2007; Posselt et al., 2019). Highlighting diverse knowledge sources and supporting varied learning styles also enable dialogue across multiple ways of knowing (Anderson and Anderson, 2020) and reflect the turn toward more transdisciplinary and holistic framings of agroecology (Mason et al., 2020).

Expanded opportunities for student agency complemented the increasingly diverse set of course materials. Encouraging student agency in course design contributes to a more participatory approach to agroecology education. This aligns with both a core tenet of transformative agroecology and with calls to expand student roles in developing agroecology education (Lieblein et al., 2012; Francis et al., 2016; Code, 2017). We see evidence of the efficacy of this participatory approach to agroecology education in the MSC reflections, in which student empowerment emerged as a forceful theme. For students accustomed to traditional Western higher education, however, the shift to a more student-centered learning process may be inherently uncomfortable (Lieblein et al., 2012; Hooks, 2014; Jordan et al., 2014; Francis et al., 2020). The potential for student frustration and discomfort when presented with greater agency in their own learning process indicates a need to build more resources and time into curricula to navigate these challenges.

PAR projects require more extensive and deeper use of reflexive practice within the course, encouraging students to reflect both in the classroom and as part of the PAR process. In their farm teams, students must navigate the inevitable unexpected bumps of participatory, applied research on working farms. Integrating reflection, research, and on-farm actions, PAR may be a way of simultaneously enabling transformative student learning and leveraging university education as a site of AE transformation toward equitable agrifood systems. This could be explored as a reinterpretation of the dual ladder approach (Francis et al., 2016) in which individual student learning occurs concurrently alongside broader, collective learning that transgresses traditional educational boundaries. Despite the challenges of integrating long-term research and undergraduate education, our course evaluation indicates that PAR holds unique promise as a pedagogical approach for transformative agroecology education.

Introducing multiple changes in course content and pedagogy would not be possible without the simultaneous shift to a teaching team model. The teaching team model diffuses the increased workload required to implement context-based and student-centered pedagogies while also bringing multiple perspectives and skillsets to cultivate a participatory and transdisciplinary learning environment. The teaching team model also provides instructors with the community support needed to navigate the many institutional roadblocks to implementing innovative pedagogies within the confines of a neoliberal university context (Anderson and McLachlan, 2016; Classens et al., 2021).

Participatory Pedagogy Is Powerful

Students appreciation of experiential learning on farms coheres with scholarship advocating for contextual, place-based learning within agroecology education (Porter et al., 2015; Code, 2017; David and Bell, 2018; Fernández González et al., 2021). Students' reports of integrating experiential and abstract learning are particularly important in addressing the ontological reversal that defines much of the theory-centric pedagogy within institutions of higher education. Francis et al. (2016) argue that a phenomenological approach to agroecology education is necessary to resituate lifeworld phenomena as the foundation for theoretical, model-based, or conceptual understanding. Considered in this context, experiential learning may support transformative learning by shifting students' perceptions of both learning processes and the validity of lived experience as a foundational source of knowledge (Francis et al., 2016). Experiential learning is intrinsically tied to transdisciplinarity (Francis et al., 2013), which further suggests transformative agroecology learning.

In the classroom, SLDs and collaboration within farm teams facilitated participatory learning, which is a core component of transformative agroecology education. Participatory pedagogies engage students as both learners *and* teachers, contributing to an educational space that works to dismantle hierarchies between knowers and learners (Lieblein et al., 2012; Code, 2017). In this sense, participatory pedagogies that integrate instructor-led and student-led lessons seem vital for transformative agroecology education.

As we suspected, course evaluations did not enable us to definitively answer our guiding question regarding the efficacy of course pedagogy for transformative learning. Nevertheless, student evaluations did provide insight into how students experienced course pedagogy. This enabled us to infer which pedagogies and student experiences may support specific aspects of transformative agroecology learning. Course evaluations also identified aspects of course pedagogy that are particularly frustrating, overwhelming, or unclear for students. This highlights opportunities for providing additional support for students to enable transformative learning from within a zone of discomfort (Galt et al., 2013b). In this way, despite deficiencies, course evaluations can be a meaningful component of both iterative course design and instructor praxis.

MSC Reflections Capture Transformative Learning

Integrated in the course for the first time in 2020, MSC reflections proved to be a valuable method for identifying and assessing transformative learning. Thematic analysis identified 5 dimensions of transformative learning: student empowerment, relationship-building, social justice learning, systems thinking, and transdisciplinary learning. Below we explore the connections

between course pedagogy and these dimensions of transformative learning. We also situate these connections in the broader context of agroecology and SFS education.

Empowerment theory (Gutierrez, 1995) suggests that by changing students' attitudes and beliefs, transformative learning may facilitate or encourage students to participate in collective action for social change (Allen, 2008). In analyzing students' MSC reflections, many linked an increased sense of empowerment and self-efficacy to a new commitment to engaging in social movements. In other instances, students connected a sense of empowerment to their future careers, expressing expanded potential to engage in professional endeavors thanks to course learning. Comparing these learning outcomes suggest there may be different layers of transformative learning. Valley et al. (2018) discuss three levels of impact in proposing their SFSESP. Our course evaluation suggests that further research is needed to explore when and how deeper transformative learning occurs that facilitates student empowerment to engage in collective action and social movements committed to agrifood systems transformation.

Engagement with issues related to social justice constituted a distinct dimension of transformative learning. Many students reflected that course learning prompted them to engage with social movements and grassroots organizing. While some students were drawn to agrifood systems issues and movements specifically, others translated their course learning and experiences into broader engagement with justice and equity, such as the movement for Black lives. A smaller handful of students discussed how course content on food sovereignty invoked a sense of responsibility to engage in equity-oriented work within future professional endeavors in food systems. This demonstrates that students in agroecology and SFS courses may apply learning in both professional and non-professional capacities, such as engagement with social movements. The potential for students to apply social justice learning beyond professional contexts is underexplored in recent scholarship on the intersection of SFSE and equity. Like SFSE in general, an equity competency model recently proposed by Valley et al. (2020) is designed to "support the development of future professionals capable of dismantling inequity in the food system." Although Valley et al. (2020) identify profoundly important educational goals and pedagogies related to equity and justice within agroecology and SFS education, our analysis suggests that the professional framing of their equity competency model may limit or obscure important non-professional learning outcomes.

Moving beyond a primarily professional framing to consider the broader impacts of agroecology and food systems education aligns with a whole systems approach. Systems thinking is frequently cited as vital for learning about agrifood systems (Code, 2017; Valley et al., 2018; Francis, 2020).

Thematic analysis of students' MSC reflections validates these assertions, identifying systems thinking as a key dimension of transformative learning. In attempting to further understand the role of systems thinking for transformative agroecology education, we consider Code's (2017) contention that systems thinking is an insufficient paradigm for developing students' ability to engage with the full complexity of agroecosystems. Code (2017) cites Bortoft (1996) critique of systems science, which highlights the paradox of breaking down living systems into artificially distinct elements in order to identify linkages. In lieu of this approach, Code (2017) draws on Schumacher (1995) proposal for a scientific paradigm of "life in its wholeness." Yet, our identification of systems thinking within students' MSC reflections aligns with this concept of a science of wholeness, suggesting that systems thinking may carry multiple meanings within agroecology and SFS education. Clarifying what is meant by "systems thinking" is imperative for developing pedagogies conducive to transformative learning.

The critique of systems thinking aligns with our findings that relationship-building is an important dimension of transformative agroecology learning. Based on thematic analysis of MSC reflections, we propose that relationship-building is a vital complement for systems thinking in agroecology education. Many students reflected on the impact that relationships had on their learning about agroecosystems. Students emphasized that the relationships they cultivated with peers and farmers during the course demonstrated the power of horizontal learning and co-production of knowledge. Based on our course evaluation, the role of relationship-building and horizontal learning as transformative pedagogies within higher education institutions warrants further exploration.

Relationship-building also enabled and reinforced transdisciplinary learning, the final dimension of transformative learning that we identified. Student reflections explored how cultivating relationships with peers and farmers transformed their perception of when, where, how, and with whom teaching and learning occur. Experiential learning on farms transgressed traditional disciplinary boundaries and provided a context for students to experience the value and necessity of integrating multiple ways of knowing within agroecosystems. Opportunities for critical reflection enabled students to integrate transdisciplinary learning within the course with their previous experiences, values, and beliefs.

Critical reflection is consistently identified as a key pedagogical tool for agroecology education (e.g., Runck et al., 2015; Francis et al., 2016; Code, 2017). In the most recent iteration of our advanced agroecology course, we expanded the role of reflection *via* the partial application of MSC methodology. The MSC reflection proved to be a valuable tool for both transformative learning and holistic course evaluation. Reflections provided rich data on student learning outcomes and enabled critical assessment of how well course materials and pedagogies supported transformative learning. Our experience adapting the MSC methodology echoes prior research in proposing MSC techniques as valuable evaluative tools in educational contexts (Choy and Lidstone (2013)). A more complete application of the method would engage students in participatory evaluation of the MSC reflections to collectively identify the MSC experienced by the class as a whole. This evaluative strategy would align with recent calls to redefine the role of students within agroecology and SFS education (Code, 2017). MSC methods also align with a more participatory agroecology pedagogy promoted by scholar-educators in Norway (Lieblein et al., 2012). As a

reflective, relational, and participatory method of evaluation, MSC techniques are particularly well-suited to identifying and supporting transformative learning (Choy and Lidstone, 2013; Acton, 2019).

We concur with Meek and Tarlau (2016) that Agroecology sustainable food system education can and should be leveraged to transform agrifood systems toward justice and ecological viability. Beyond training a workforce capable of engaging with agrifood systems as they currently exist, education provides a venue for forming individuals capable of supporting such transformations. This is evident in the concept of *formación* that guides popular education initiatives led by social movements in Latin America. *Formación* corresponds to training or educating toward a transformative purpose (McCune et al., 2017). Formal agroecology and sustainable food system education in the U.S. can serve a similar role, providing liminal spaces that expose students to alternatives to the oppressive and extractive systems in which they are embedded. In this way, agroecology courses may constitute a "domain of transformation" (Anderson et al., 2019a) where agroecology overlaps and interfaces with the dominant regime—in this case, neoliberal institutions and traditional "knowledge transfer" approaches to agricultural education. In domains of transformation, there are simultaneously factors that enable *and* disable transformative processes; the reality of the latter does not inherently negate the potential of the former (*ibid*). The tension of teaching transformative agroecology from within the academy may also be clarified through the lens of non-reformist reforms, which prefigure transformation *via* smaller shifts that cumulatively enable broader change (Gorz, 1967). Viewed in this way, courses that facilitate transformative learning may cultivate young adults who, at best, are prepared to stand in solidarity with collective struggles for transforming agrifood systems toward justice and equity, and who, at a minimum, are more aware of -and thus more open to- alternatives to the dominant, industrial agrifood system. By contributing to a shift in whose knowledge and expertise are valued, transformative agroecology education also contributes to thick legitimacy for agroecology more broadly (Montenegro de Wit et al., 2016).

Additional Considerations

This paper evaluates an agroecology course taught in the Northeastern U.S. and is intended to assess and improve student learning. The goal of sharing evaluative results, processes, and insights is to contribute to a broader movement of scholar-educators committed to iteratively and collaboratively developing transformative pedagogies within Agroecology sustainable food system education (Galt et al., 2013b). To that end, we find it necessary to identify unique factors that call for further consideration and evaluation, both within our own course and in the design and evaluation of other courses.

First, the integration of the course with a long-term PAR project conducted in collaboration with multiple farmer partners results in a diversity of students' on-farm learning experiences. Over the years, course instructors intentionally engaged a diversity of farmers and farm types to expose students to the multiple manifestations of agroecological practice. This also provided an opportunity for peer-to-peer learning as students were able to share their experiences with students assigned to other farms. In the context of evaluating transformative learning, however, the range of students' on-farm experiences may impact student learning. In future iterations of course evaluation, assessing student learning grouped by farm teams may provide insight into whether some farm experiences are more conducive to certain types of learning.

Second, a substantial portion of our evaluation was based on MSC reflections submitted by the most recent cohort of students who took the course in fall semester 2020. The course took place as the world was weathering a deadly pandemic and the U.S. was experiencing widespread protests of racial injustice. Amidst this extraordinary backdrop, it is possible that students were more open to certain kinds of learning. For example, multiple students protested police violence and participated in the movement for Black lives. These experiences likely influenced student learning, contextualizing course materials and pedagogies designed to encourage collective action for social justice. The influence of current events on students' lives and learning highlights the importance of reflexive practice for situating learning and learners within the world beyond the classroom.

Finally, the questions guiding our course evaluation focused explicitly on identifying and assessing transformative learning. This enabled us to deeply explore the alignment of both course pedagogy and student learning with a transformative approach to agroecology. At the same time, however, we did not dive deeply into the full spectrum of student experiences. Future work could integrate assessments of transformative learning within a broader exploration of student experience and outcomes.

CONCLUSION

In evaluating transformative learning, we observed and reflected on the ways that agroecology education transcends professional preparation to shift students' perceptions of agrifood systems and their place within them. Yet U.S.-based agroecology and food systems scholarship tends to focus on cultivating students as food systems professionals. The reasons for this are multifaceted and complex, and hence difficult to resolve. They include western scientific epistemologies that reject transformation as part of their mission, tension with the neoliberal bent of many universities, and the reluctance of instructors to engage with what could be perceived as political or activist content. Our course, which applies many of the same pedagogical innovations currently leveraged for professionalization, suggests that transformative learning is occurring. This is particularly important in the context of undergraduate education. Many undergraduate students may not go on to work as professionals within food systems, and those who do may need different skills and competencies in the future than those currently emphasized in agroecology and sustainable food system courses and programs. Expanding educational goals and evaluative methods will enable scholar-educators to identify and unpack the

deeper impacts of innovative food systems education currently practiced in multiple pockets throughout the U.S.

Cycles of critical, collective reflection have informed our conceptualization of the purpose of agroecology education which, in turn, informs our pedagogical approach. We perceive education as a critical component of transformative agroecology more broadly. We therefore seek to align course pedagogy and student learning with the tenets of transformative agroecology as we understand it: transdisciplinary, participatory, action-oriented, and political. A teaching team model serves as the foundation supporting our pedagogical approach, which is built around a framework of experiential learning on farms. As a foundation for the rest of the course, the identities and structure of the teaching team matter greatly. Including farmers and graduate students models a more inclusive and transdisciplinary approach that contributes to dismantling traditional hierarchies of knowledge and expertise. Future work should explore how teaching teams form, interact, and mediate pedagogy and student learning.

Innovations in pedagogy require synergistic innovations in evaluative methods. Traditional course evaluations administered by colleges and universities do not provide opportunities for in-depth, critical reflection on individuals' learning outcomes Choy and Lidstone (2013). To address the deficiency of standard course evaluations, we complemented 10 years of student comments on university evaluations with most significant change (MSC) reflections. MSC methods are uniquely capable of identifying unintended, complex, and diverse outcomes of a program or intervention and provide a means of qualifying and dignifying anecdotal evidence of transformative impacts (Dart and Davies, 2003). MSC holds potential as an evaluative method aligned with transformative agroecological goals to democratize knowledge and dismantle top-down educational approaches that impose predetermined evaluative metrics.

Our analysis of student MSC reflections indicates that agroecology education can contribute to developing students' political subjectivities as actors embedded within agrifood systems. This suggests the need to critically explore the purpose(s) of agroecology and SFS education beyond professionalization. We propose that a key goal of agroecology education is one of ontologically reembedding students within agroecosystems and cultivating their identities as more-than-consumers (Anderson et al., 2019b). Emphasizing an ontology of interconnectedness (Vargas Roncancio et al., 2019) will further enable agroecology education to explore power and responsibility beyond the false binary of producers and consumers and will encourage students to examine the roles of relationships, solidarity, and sovereignty movements within food systems.

We contend that agroecology education can be an important site for movement building. As noted above, students may develop expanded political consciousness and a sense of self-efficacy that spur engagement with struggles to realize socially and ecologically sustainable food systems. We also support and expand on Galt et al.'s (2013b) proposal for a movement of sustainable food systems educators. Our case study demonstrates the importance of the teaching team model as a foundation for implementing pedagogies for transformative learning. Collaboration and solidarity amongst instructors implementing innovative pedagogies may function as a compass in navigating the many challenges to designing and implementing courses and programs capable of contributing to broader processes of agroecological transformation.

DATA AVAILABILITY STATEMENT

The data analyzed in this study is subject to the following licenses/restrictions: We analyzed student essays and student evaluations as part of a course evaluation to improve course design and student learning. Student work is not publicly available. Course syllabi are available upon request. Requests to access these datasets should be directed to Catherine E. Horner, chorner@uvm.edu.

AUTHOR CONTRIBUTIONS

CH led the acquisition of data, data anlaysis, and drafting of the manuscript. NC and CM contributed to writing and revising the manuscript and provided critical feedback on multiple drafts. NC, CH, and KN created all figures. KN, TM, MC, EK, JF, VI, VM, SL, and NM provided substantial contributions to the conception and design of the work and provided substantive critical feedback on multiple drafts, improving the intellectual quality of the work. All authors contributed to data interpretation and revisions.

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