1-21-2023

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Received: 6 June 2022 | Accepted: 21 January 2023
DOI: 10.1002/nse2.20101

Natural Sciences Education

SPECIAL SECTION: COVID-19 FORCED RAPID CHANGES IN EDUCATION, BUT WHICH CHANGES SHOULD WE KEEP?

Refined teaching methods, systems thinking, and experiential approaches enhanced students learning through COVID-19

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Assigned to Associate Editor Bethann Garramon Merkle.

Abstract

The Soil Nutrient Relationships course serves juniors and seniors with a major or minor in agronomy at the University of Nebraska-Lincoln. Pre-pandemic enrollment averaged 65 students. In 2021 and 2022, course enrollment was 42 and 55, respectively. The course was adjusted to a flipped design in 2017. Moving into 2021, the Soil Nutrient Relationships course underwent a major overhaul by changing the content source materials and organization of lab activities while maintaining the flipped delivery format. While responding to the COVID-19 pandemic limitations, the redesign was intended to focus limited face-to-face meetings (in person or web-conference) on problem-solving activities. This paper reports on course redesign emphasizing changes for and since the pandemic. Surveys were used in both 2021 and 2022 to assess students' learning and reception to the course design. In surveys, students responded that they gained knowledge in all course learning objectives and increased both problem-solving and systems approach skills. The overall responses were similar between 2021 and 2022; however, one difference was that students placed a higher value on the in-person discussion and lecture in 2022 relative to Zoom discussion or video lecture in 2021. Despite working on similar problem-solving activities, 81% responded that discussion helped with problem solving skills when done via Zoom in 2021 while 88% responded that in person discussion helped with problem-solving skills in 2022. Smaller group sizes used in 2021 seemed to improve student opinions of learning; this is the one change that instructors plan to use in the future.

1 | INTRODUCTION

Much of the agricultural industry works to continually pinpoint issues that need improvement and solve the interrelated problems that will follow. For students in agriculture, their education must teach them to be more effective at evaluating the whole system and taking steps to resolve these problems. It is beneficial if the learning environment emphasizes real-world problems and improvements, outreach into farming communities, and continual updating and adaptation of curriculum to reflect the current environment (Bawden, 1983; Bawden et al., 1984; Ginzburg et al., 2019; Hiller Connell et al., 2012; Kolb, 2014).

Agricultural, sustainability, and social problems tend to be interdisciplinary, nonlinear, and complex, which requires integrating systems thinking into the problem-solving process (Anderson et al., 2022; Dale & Newman, 2005; Holling, 2001; Wiek et al., 2011). Preparing students to utilize systems thinking in their professions is of utmost importance (Martin, 2008; Monroe et al., 2015; Wiek et al., 2011). Systems thinking is a skill that must be taught (Hung, 2008). With teaching systems thinking, the main obstacle to address is helping the students to integrate multiple perspectives to organize and evaluate a complicated problem. Holistically viewing an issue or problem requires acknowledging and finding these interrelated and interdependent perspectives to determine a solution (Cloud, 2006; Dale & Newman, 2005; Ellis & Weekes, 2008; Hiller Connell et al., 2012).

The Soil Nutrient Relationships course offers unique opportunities for implementing systems thinking and experiential learning approaches given its scope. The Soil Nutrient Relationships course is framed within the four R's Nutrient Stewardship principles (IPNI, 2022), which include the implementation of right sources, right rates, right times, and right methods of nutrient management applications in agriculture. This framework is fundamentally important as it has a direct impact not only in agriculture itself, but also in the economic, environmental, and societal outcomes. Altogether, the 4R Nutrient Stewardship programs are intended to provide a robust working framework for the achievement of successful cropping system through higher production, increased profitability, enhanced environmental protection, and improved sustainability.

Despite many possibilities that exist for enhancing systems thinking, the COVID-19 pandemic limited options. The onset of the COVID-19 pandemic created major challenges and uncertainties in the classroom (Brown & Krzic, 2021; McKim et al., 2021; Walker & Koralesky, 2021). In-person contact had to be limited, therefore schools and universities had to pivot to online teaching completely or a hybrid of online and in-person teaching, depending on location and university requirements (Moorhouse & Tiet, 2021; UNESCO, 2020; Wilson, 2020). Transitioning to all online teaching was quite challenging, especially for those classes that relied on experiential learning and participatory based teaching styles (Moorhouse & Tiet, 2021; Wilson, 2020). Many teaching strategies that were utilized in face-to-face classrooms were either no longer possible or made harder in online teaching. The strategy of using small group activities and discussions were not as accessible if the online class was being taught asynchronously, which decreased the students' ability to learn from each other and expand their perspectives (Tang et al., 2020; Wilson, 2020). Teachers had to overcome the challenge of not being able to effectively utilize non-verbal cues (e.g., facial expressions, body language, gestures) from their students to gauge understanding and provide additional assistance where needed due to classes being held over video call (Cutri & Mena, 2020; Wilson, 2020).

Core ideas

- The flipped model facilitated teaching problem-solving in a content heavy course during the COVID-19 pandemic.
- Students placed greater value on in-person learning activities than independent or web-conference learning activities.
- Small group learning necessitated by the COVID-19 pandemic correlated to greater learning than larger class sizes.

Moving into 2021, the Soil Nutrient Relationships course underwent a major overhaul by changing the content source materials and organization of lab activities while maintaining a flipped delivery format. In addition, in the same year, changes were needed for responding to the COVID-19 pandemic. The redesign was intended to focus face-to-face meetings (in person or web-conference) on problem-solving activities. Surveys were used in both 2021 and 2022 to assess students' learning and reception to the course design. This paper reports on course redesign emphasizing changes for and since the COVID-19 pandemic with the objective of identifying lessons learned to be implemented in future teaching.

2 | METHODS

2.1 | Course description

Soil Nutrient Relationships (AGRO/SOIL 366) is a junior–senior level course at the University of Nebraska-Lincoln required by most options of the Agronomy major and minor (minors are typically majoring in agricultural business/economics or mechanized systems). The content focuses on understanding the cycling of nutrients to better address practical nutrient management situations. The course builds on concepts from 100-level introductory soil science (prerequisite to this course) and 200-level departmental courses on crop and soil management. The course is framed within three key areas: (1) systems thinking, (2) experiential learning, and (3) problem-solving. This approach provides students (and future decision makers) with proactive resources for successful careers in agriculture.

2.2 | Course history and demographics

The course is offered once a year, in the Spring Semester, and for many years its enrolment average was 65 students. This course typically has ∼10 students who are not from the United States (US), this smaller group represents several other countries (e.g., China, Mexico, Rwanda). Across the entire class, it is common for the students to come from farming backgrounds, and a majority plan to go back to the family farms after they graduate. Those who do not go back to their farms often work for private agricultural companies, and a very small portion choose to pursue postgraduate studies. Regardless of the path they take, they become the decision-makers in day-to-day operations for the years and decades to come.

2.3 | Course goals

The overarching goal of this course is for students to be able to formulate evidence based nutrient management plans that consider the three pillars of 4R Nutrient Stewardship: economics, society, and the environment (IPNI, 2022). The course is intentional about training students to be able to use and apply nutrient management concepts in real-world settings. Within the broader goal, specific course learning objectives include developing and mastering the ability to understand the following:

- Nutrient cycling and the factors affecting availability of major nutrients.
- Limiting factors for various nutrients in various environments.
- How/where to obtain data and science-based recommendations for nutrient management.
- Integrating nutrient management as a systems approach.
- Use of the 4R Nutrient Stewardship scientific approach.
- How socio-economic factors affect nutrient management decisions.

2.4 | Course assessments and grades

This four credit course has typically used two 1-h large group sessions for lectures, discussion, problem examples, and case studies as well as one 2-h session of smaller groups (labs) to work on relevant skills (e.g., soil sampling plans, soil test interpretations) per week. In general, the course has used a weekly online quiz over lecture videos, a weekly in-person quiz over lab activities, 5–6 assignments over specific tasks, attendance at case study discussions, a nutrient management project, and three exams for graded assessments (Table 1). The content knowledge (e.g., soil pH, nitrogen cycle, manure management) was assessed with weekly reading quizzes and three exams. Specific skills (e.g., writing a soil sampling plan, calculating phosphorus rate) were assessed with unit assignments and weekly lab quizzes. The problem-solving was assessed with unit assignments and the comprehensive development of a project through all the duration of the course.

2.5 | Course transformations in the last six years

2.5.1 | From traditional to a flipped model (2017–2020)

The course was first transitioned to a flipped design in 2017 (Keck et al., 2021). That design required students to watch prerecorded lectures online and come to the class prepared to work on solving collaboratively applied concepts, real-world scenarios, and case studies. Some of the key takeaways from this transformation included: (1) overall student engagement was increased through opportunities to solve problems during class time, (2) students responded positively to the learning experience even though the workload increased, and (3) student scores on key assessments were similar before and after flipping the course (Keck et al., 2021).

2.5.2 | Refined teaching models during the COVID-19 pandemic (2021–2022)

Changes to instructive personnel combined with a need to adapt to university expectations for decreased in-person contact during the COVID-19 pandemic resulted in a reorganization of the Soil Nutrient Relationships course (Figure 1). The course continued to use a flipped design but elevated the goal of enhancing systems thinking while also adopting new resources for content learning, and updating lab to better coordinate with weekly course content. The redesigned course had the following goals:

1. Maximizing flexibility to allow both for changing conditions during the pandemic and for students who chose to work (or farm) full time during parts of the semester.
2. In-person activities should prioritize problem-solving, as prior studies indicated that lower level learning can be done independently but analyze, solve, and apply types of learning are best done with instructor's guidance.

Given the pandemic, the teaching team needed to reassess the existing methods and adapt promptly to new methods

TABLE 1 Assessment items, percent of final grade represented on each item, and the description. This information is included to students on the syllabus of the class.

Assessment items	Final grade (%)	Description
Weekly quizzes	20	These quizzes include each respective week's content from reading and videos as well as lab content and calculations. Content quizzes are online and lab quizzes are taken during lab.
Unit assignments	15	Summative assignments would include questions replicating in-class activities for independent work. Assignments will include sketches, reflections, and developing smaller scale nutrient management plans.
Case study reports	10	Students work with a team to assess a situation and summarize findings in a brief oral report. Points are assigned for attendance and participation.
Nutrient management project	25	This project is a summative nutrient management project where students apply the soil nutrient management concepts and skills they learn in this course. Of 25%, 20% accounts for a final written report and 5% for an oral presentation/defense of their work.
Exams	30	A total of three exams are given during the semester. The exams format includes multiple choice, short-essay questions, matching, and calculations. Exams are independently administered online, open book, and with limited response time.

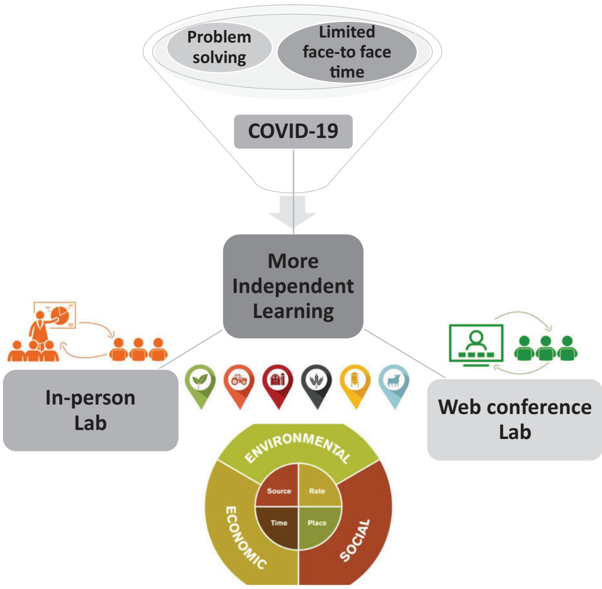

FIGURE 1 Refined teaching methods after accommodations were made during the COVID-19 pandemic, this new method was first implemented in the middle of the 2020 Spring Semester and in full during the Spring Semesters of 2021, 2022.

(Table 2). Such adaptation included converting more of the course to online (e.g., independent learning) formats and re-packaging many of the lecture and lab items. The course update was accelerated due to transitions from the COVID-19 pandemic in the middle of the Spring 2020 and implemented in full during the Spring of 2021, 2022. Such transformations involved shifting from reliance on instructor's in-person lectures to using a textbook (made available to the class digitally) for content delivery on their own (i.e., independent learning). There was minor adjustment in the course topics and major changes were brought to the activities and assessments. In the refined approach (Table 2), students still reviewed basic concepts on their own and worked on problem-solving during class time.

2.6 | Course surveys

There were two surveys used in 2021 and 2022, both were administered through Canvas for bonus points if completed. The first was a learning survey and included 66 questions about course content (e.g., describe the factors used in deciding if lime application is needed, convert from ppm to pounds per acre). Survey respondents were asked to select "A" if they felt confident that they could answer the question or perform the task indicated, "B" if they could answer 50% of the question or knew precisely where they could get the information in 30 min or less, or "C" if they were at a loss as to how to answer the question. This survey was administered at the beginning and end of each semester. Each A response was weighted as 1, B as 2, and C as 3 to develop an average ranking for each question where lower scores indicated greater student confidence with that content. The average rankings were then compared from beginning to end of each semester. The end scores from each semester were also compared to each other. With this data, instructors were able to quantify the knowledge gained for various learning objectives in each semester and compare learning between the semesters.

The second was a course survey that focused on content delivery approaches. This expanded on the survey tool used in Keck et al. (2021) with questions for engagement with and appreciation of the various learning materials and opportunities that students were provided (e.g., textbook, in-person lab). This survey also included questions on meeting the broader course and department student learning objectives. Most survey questions used a five point Likert scale of "strongly agree", "agree", "neither agree nor disagree", "disagree", and

TABLE 2 The when, what, and how of the refined teaching during the COVID-19 pandemic.

When?	What?	How?
First part of the week	Independent readings	– Review basic concepts on fertility management practices as the assigned reading (textbook and Nebraska Extension Guides, all digital). – A quiz over the assigned content was taken before the first meeting, designed as 60% recall and 40% comprehension. – Any concerns observed from the quiz statistics were reviewed during in-person meetings. – Each week included a lecture from the course instructor on local application of text concepts. In 2021, the lecture was via video while in 2022, the lecture was in-person. – The in-person lecture period for 2022 included open-ended discussion questions and example calculations.
In the middle of the week	Lab activities, small groups (3–4 students per group)	– This emphasized activities that involved calculations or other skills where instructor's help would be useful. – Labs were repackaged from older labs and prior case studies to ensure that all calculations were done during in-person small group meetings. – Lab skills were assessed via short quiz in the following week's lab. – Lab activities contributed to small assignments and the larger performance task activity (project).
At the end of the week	Practical problems and solutions discussion, small groups, instructors and students	– Identify complicated or unknown factors and develop potential solutions with a sound rationale. – Each of these were small versions of achieving one of the broader course goals (developing a nutrient management plan for a specific farming scenario). – By working on smaller problem sets and presenting justification regularly, students were better equipped to justify their overall project at the end of the semester. – The discussions were conducted via web-conference (Zoom) in 2021 and in-person in 2022.
On their own time	Small groups, 3-4 students per group, Nutrient Management Project	– Performance task, one of the main course learning goals. – Most of it conducted outside of class time, occasional meetings with the instructor(s) to discuss progress and issues. – Students had directions and a detailed rubric to follow. – Portions of the project were due each month to ensure adequate progress. These monthly submissions were reviewed by instructors and peers to provide timely feedback that improved the final project outcome. – Instructors kept track of suggestions made versus changes made to each project, this was one of the final project evaluations criteria.

"strongly disagree." Some questions asked students to rank the usefulness of various resources (e.g., the textbook or activities in lab). A weighted average of students' responses was determined to compare the overall rankings. A final set of questions asked students for their perception of the learning level achieved when engaging in each activity. Students were able to select from a five point scale and were provided with the following guide to learning levels:

Was the activity more about learning facts (learning level 1), or about applying facts to new situations (learning level 3), or about combining facts to solve complex problems (learning level 5)?

This survey was administered at the end of each semester to understand how various content worked for the students. Because of the changes in course delivery postpandemic, the 2022 responses were only compared to the 2021 responses.

3 | RESULTS AND DISCUSSION

3.1 | Survey results for perception of learning

The amount of learning was assessed with a knowledge survey administered at both the beginning and the end of the course in 2021 and 2022. When comparing beginning to end survey responses, the amount of learning did not differ between years. In both years, there were 15 topics with gains greater than one (e.g., from 2.5 to 1.4) which indicates learning during the semester and the two topics with the biggest improvement directly represented the overarching course goals of applying soil information to make management recommendations. Those topics were as follows:

- Calculate lime rate based on soil test information and lime quality data (2021: initial: 2.56, final: 1.29) (2022 initial: 2.52, final: 1.41)
- Develop a nutrient management plan using the 4R scientific principles for nutrient management. (2021: initial: 2.487, final: 1.161) (2022 initial: 2.42, final: 1.21)

The topics with little change in knowledge from the beginning to the end of the course were similar for both year's surveys and appear to be due to high student confidence when entering the course. There were some small differences when comparing just the end survey responses from 2021 to 2022. The largest difference was positive 0.31 indicating that content was less well understood in 2022 than in 2021. There were eight other topics with differences greater positive 0.20. There were few topics with negative differences, the greatest was negative 0.16. Therefore, it seems that most content was learned similarly between years, but some topics were slightly better understood in 2021. The learning survey data results will mostly be used to guide future efforts for course content delivery (e.g., improving lab activities for some content, and reducing lecture time for other content).

The course survey also directly asked students about course and departmental learning objectives. For both years, over 89% of survey respondents agreed or strongly agreed that the course improved their knowledge or confidence in all eight course objectives that they were surveyed over (Table 3). Additionally, students were asked about how the course increased their knowledge or confidence for the 18 departmental learning objectives (as this course is required for all majors).

Several departmental objectives address solving complex problems and a high percent of respondents agreed or strongly agreed that the course improved their knowledge or confidence in those departmental objectives (Table 4). In general, students and the department value this course for developing problem-solving skills for practical agronomic application. It appears that this was upheld throughout the COVID-19 pandemic and post-COVID teaching adjustments.

Responses to these surveys indicate that students learned during the new model. Course goals were achieved even with limited in-person interaction during the 2021 semester. Instructors were not surprised that some topics had worse learning scores (measured as positive differences in end survey responses) in 2022 than in 2021 as they observed differences in quality of written work during the semester. There are two possible explanations. For one, the 2021 students may have just been academically stronger. Enrollment was lower during the pandemic and probably, only the most academically minded students continued their education. A second explanation is that smaller groups were also used in 2021. The 42 students were spread over four labs and two lecture sections while 2022 used two labs and one lecture section for 55 students. Multiple other studies of college courses have found that student success increased when class size was smaller compared to larger class sizes (Arias & Walker, 2004; Ehrenberg et al., 2001; Millea et al., 2018).

3.2 | Survey results for perception of course approach

As students do not possess the skills to elevate their learning (Burke & Fedorek, 2017), flipped classrooms are the most successful when independent activities are used for the learning of facts and classroom activities are used to connect and apply concepts (Bergmann & Sams, 2012; Brevik et al., 2022; Keck et al., 2021; O'Flaherty & Phillips, 2015; Sindelar et al., 2022). The course content was entirely online in 2021 with meetings used only for problem-solving. In 2022, the course added one lecture per week (on application of content) to its flipped design. This change in delivery

TABLE 3 Percent of respondents who agree or strongly agree that Soil Nutrient Relationships course improved their knowledge or confidence in the following course learning objectives in each course year.

Learning objectives	2021	2022
Formulate an evidence based nutrient management plan that considers economics and the environment.	97	100
Describe nutrient cycling and the factors affecting availability of each nutrient.	97	98
Describe limiting factors for various nutrients in various environments.	97	98
Describe how to obtain appropriate data and science-based recommendations for nutrient management.	94	90
Describe integrating nutrient management as a systems approach.	89	96
Describe use of the 4R scientific approach.	97	98
Describe how socio-economic factors affect nutrient management decisions.	92	92
Work in groups to analyze agronomic situations and solve agronomic problems.	92	90

Note: Thirty six of 42 students completed the survey in 2021. Fifty one of 55 students completed the survey in 2022.

TABLE 4 Percent of respondents who agree or strongly agree that Soil Nutrient Relationships course improved their knowledge or confidence in the following select departmental learning objectives.

Learning objectives	2021	2022
Understand that plant and soil systems are embedded within complex social-ecological networks that interact across a range of spatial and temporal scales.	92	94
Understand the difficulty in managing complex systems.	97	92
Demonstrate understanding and problem-solving based on the concepts and applications of their area of study.	94	94
Interpret graphs, charts, and tables and communicate results through written and oral reports.	95	90
Lead and contribute to diverse teams to propose and implement solutions to complex plant and soil system problems.	86	84

Note: Thirty six of 42 students completed the survey in 2021. Fifty one of 55 students completed the survey in 2022.

changed the perception that students had of several course materials and activities. As for materials, one expected difference was the decreased value that the students placed on the course textbook when provided with in-person lectures in 2022 as compared to the more independent learning approach in 2021. The percentage of students who reported that they had "interactions that increased their learning" with the textbook decreased from 67% to 59% of respondents.

Additionally, students were asked to rank the value of various course materials. The textbook's average ranking in 2021 was third, while it dropped to fourth in 2022 (Figure 2). The item that increased in value to students was access to lecture slides. The lectures themselves were rated No. 1 each year even though delivered in person in 2022 and via recorded video in 2021. The slides were more useful to students with the in-person lecture. Another course material that was less valuable to students in 2022 was calculation help videos (where instructor worked out example problems using video capture on a touch screen). The percentage of students who reported that they had interactions that increased their learning with the calculation help videos decreased from 81% to 66% of respondents. While these videos remain helpful for a portion of students and will be accessible to all the students via Canvas, the number of students who found value in them decreased with the increase in in-person meetings in 2022.

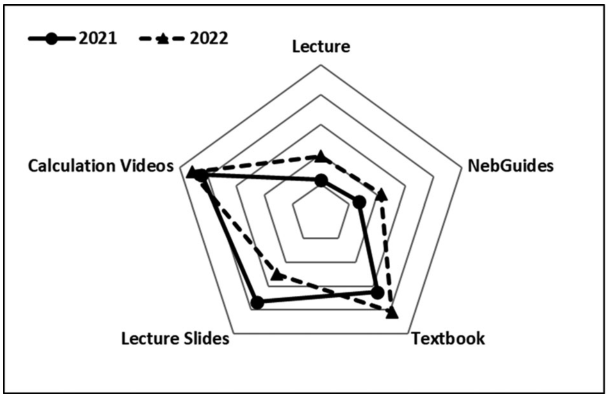

FIGURE 2 Mean ranking for usefulness of course materials toward students learning. Students would rate the most useful material as 1, and use greater values for less useful materials. Student responses were averaged to find a mean rating for each item each year.

In a survey about student experience in a flipped classroom, Keck et al. (2021) found that over half of the respondents felt

TABLE 5 Percent of respondents who agree or strongly agree with the following statements about their learning during lab activities in Soil Nutrient Relationships course.

Statements about lab activities	2021	2022
You were motivated to attend lab.	94	86
You felt a sense of community with your lab group.	81	84
Attending lab gave you the chance to ask questions.	95	84
Lab activities were a good use of your time.	94	84
Lab activities increased your learning.	92	86
Lab activities helped you solve agronomic problems.	86	86
Lab activities helped you apply textbook concepts to practical situations.	75	76
Lab activities improved your grade on exams.	94	88
Lab activities improved your grade on assignments.	97	88
Lab activities improved your grade on the course project.	86	78

Note: Thirty six of 42 students completed the survey in 2021. Fifty one of 55 students completed the survey in 2022.

motivated to access video content outside of class. Despite this, when the video viewing history data was evaluated, instructors found that as the semester progressed, students' interaction with video content decreased from 79% in the first week of class to 38% in the last week of class (Keck et al., 2021). Similar results were found in other studies, with reasons for the decline in student interaction with online or video content outside of class being attributed to issues such as, provision of lecture slides in addition to video leading students to believe they had the information they needed, and did not need to watch the video, and quizzes could be passed without watching the videos due to information on slides or level of difficulty of assessment (Radunovich & Acharya, 2018).

A similar analysis was conducted for course activities. In both years, students ranked lab as the No. 1 activity for increasing their problem-solving skills. In 2021 (when lab was the only in-person meeting), students also ranked lab as No. 1 for increasing the amount they learned with independent activities (reading text, watching videos, etc.) as second most valuable toward learning. "Lecture" was not a choice in 2021 and was lumped in with independent activities. As one in-person lecture was conducted each week in 2022, this was offered as a choice and selected by students as No. 1 for increasing the amount they learned while lab decreased to second place and independent activities (now text only) dropped to the lowest ranking. It is difficult to do a comparison of the rankings between years since there were more choices in 2022.

The decreased appreciation for lab activities was also captured in student responses to Likert questions about lab (Table 5). Student responses decreased for motivation to attend lab, perceived usefulness of lab, and perceived learning in lab from 2021 to 2022. The greater appreciation of lab in 2021 is driven by it being the sole opportunity for in-person learning, which students place high value on (Keck et al., 2021; Moravec et al., 2010; Wilson, 2020). Other activities were done in-person in 2022 as well which decreased student's perception of lab.

One activity that was done via web conference (Zoom) in 2021 and brought back to in-person in 2022 was weekly discussion of application and case studies. The student perception of discussion activities increased (Table 6) even though the discussion problems and course assessments were the same in each year. Survey respondents were more likely to agree that discussion activities increased their learning, improved their grade on assignments and exams, and developed a sense of community than respondents in 2021. Students also reported greater motivation to attend discussion in 2022; however, actual attendance was lower than 2021.

The survey responses for student perception of discussion do not match with instructor perception. While discussion was done in-person in 2022, it was also done at a much greater student to instructor ratio (42 students in two lecture sections in 2021 vs. 55 students in one lecture section in 2022) with the burden to elevate learning pushed back onto the student as instructors were not able to spend as much time checking and discussing with individual groups. Interaction with peers was similar in both years as students worked in small groups. In the course survey, students were directly asked what learning level they had achieved in various course activities with one being the lowest (memorizing facts) and five being the highest (combining facts to solve problems).

For overall learning and all other course activities, there was no difference (data not shown, no statistics performed) between years. However, the student's perception of their learning during discussion activities averaged 2.80 in 2021 and 3.52 in 2022. This data directly reflects the bias that students have for in-person learning. A study of an agricultural science course also found that when implementing a flipped classroom, student enjoyment in the course decreased 43.6% compared to traditional all in-person learning, while multiple surveys of medical students also reported diminished

TABLE 6 Percent of respondents who agree or strongly agree with the following statements about their learning during discussion in Soil Nutrient Relationships course.

Statements about discussion[a]	2021	2022
You were motivated to attend discussion.	69	75
You felt a sense of community with your discussion group.	80	96
Attending discussion gave you the chance to ask questions.	64	73
Discussion activities were a good use of your time.	64	77
Discussion activities increased your learning.	73	87
Discussion activities helped you solve agronomic problems.	81	88
Discussion activities helped you apply textbook concepts to practical situations.	64	77
Discussion activities improved your grade on exams.	64	81
Discussion activities improved your grade on assignments.	75	89
Discussion activities improved your grade on the course project.	78	79

Note: Thirty six of 42 students completed the survey in 2021. Fifty one of 55 students completed the survey in 2022.
[a]Discussion activities were conducted via web conference in 2021 and in-person in 2022.

satisfaction in online learning opportunities compared to in-person (Al-Balas et al., 2020; Baticulon et al., 2021; Keck et al., 2021). With identical activities and less instructor interaction, there is no reason that learning would actually be greater, however, the student perception of it was greater. Discussion activities are graded for attendance only, so performance cannot be compared. In both years discussion was one of the lower ranked items for the questions about which activities increased learning and problem-solving.

3.3 | Justification of the transformed teaching methods

Many scientific documentation sources have pointed out the major need for students to understand complex, dynamic, and challenging systems across different sectors, including those related to agriculture (Jacobson & Wilensky, 2006; Mennin, 2010; Monroe et al., 2015; Riess & Mischo, 2010; Runck et al., 2015; Vosniadou & Brewer, 1992). Providing opportunities for experiential learning and application of the principles of systems thinking allows a deeper understanding and better development of skills (Bawden et al., 1984; Ginzburg et al., 2019; Hiller Connell et al., 2012). Experiential learning teaches students to think about their subject and all its interactions outside of the classroom (Ginzburg et al., 2019). There are some basic facts that students need to learn (e.g., nutrient chemistry) but the course overwhelmingly is about systems thinking and problem-solving as each and every time that they will determine nutrient plans in their future will be a unique situation for which course instructor(s) cannot provide a prescription. Teaching systems thinking should not be viewed as an "add-on" to an education, but rather needs to be integrated throughout the course and even the entire curriculum (Hiller Connell et al., 2012). Students need to know what questions to ask and what data to gather so even if providing them with all the questions is not effective, they must develop some questions on their own.

The case studies practiced in class directly contribute to this schema. Students make smaller plans where they are provided with some specific data and inputs, yet not covering the entire situation. Therefore, students are prompted to find other resources with additional information and input before being able to develop justifiable and sound management recommendations. Part of this process also includes developing goals for each situation, for example establishing achievable yield goals and planning nutrient applications accordingly. In the surveys, 86% (both years, Table 5) reported that lab activities helped them solve agronomic problems while 81% and 88% (Table 6) reported that discussion activities helped them solve agronomic problems. The course was redesigned to emphasize problem-solving activities during meeting times and this appears to have been successful (90% or greater reported increased confidence for "work in groups to analyze agronomic situations and solve agronomic problems" in each year; Table 3). The difference in valuing discussion toward problem-solving again comes because the discussion activities were via Zoom in 2021 but in-person in 2022.

3.4 | Plans moving forward

The overall format for organization and delivery developed in 2021 was used in 2022, and it will continue to be used in coming years (Figure 3). This represents a semi-flipped design with content learning done independently and only one lecture per week focused on application of content. Most course meetings are used for problem-solving in small groups.

While the students valued engaging in discussion activities in person more than they did via Zoom, it was clear to the

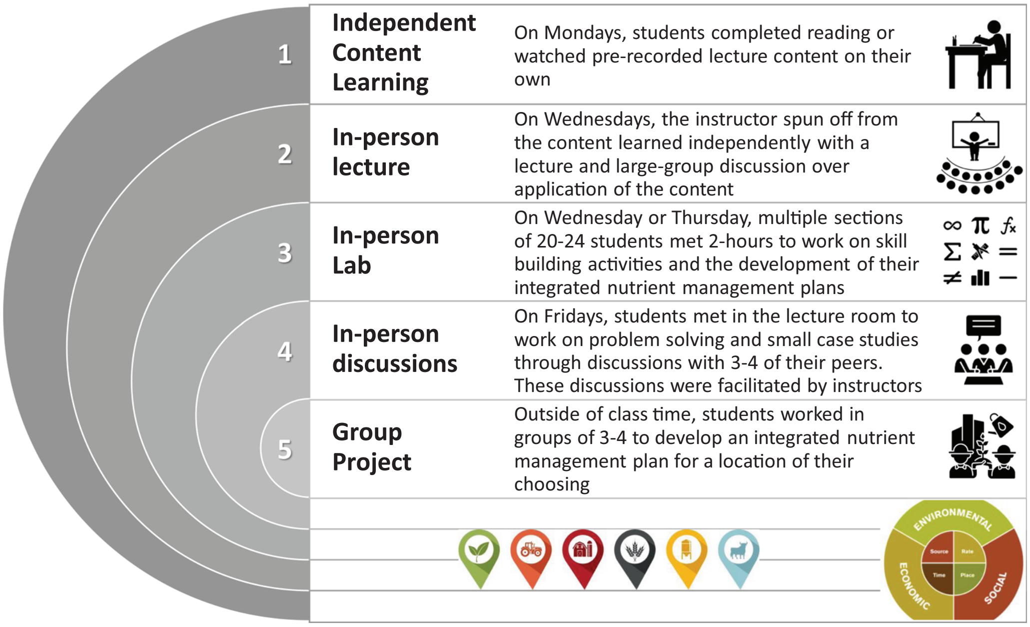

FIGURE 3 Enhanced course structure after refined teaching methods were implemented during the COVID-19 pandemic during the spring semesters of 2021 and 2022. The enhanced mode was driven by the desire of increasing systems thinking approaches among the students. The enhanced structure will continue to be used in coming years.

instructors that the in-person meetings did not elevate learning to the same degree as the Zoom meetings had. The difference was most likely from differences in the student to instructor ratio. When meeting via Zoom, class was divided into two sections with the average student and instructor attendees 20 and two, respectively per section. With students in breakout rooms of four, and both instructors going to breakout rooms to discuss content with students, ~40% of class time was 4:1 (student to instructor) interaction.

However, when returning to in-person meetings (Spring 2022), there were 40–50 students and two (but sometimes only one) instructors. While students still worked in small groups and instructors still had individual discussions with each group, the direct interaction for each student group was reduced to less than 10% of class time. While we intentionally made accommodations to effectively work with 45 students via Zoom in 2021, we see now that we did not do enough to effectively work with 45+ students in person in 2022. The goal going forward will be to convert these discussions to two smaller classes and make sure that there are two instructors to increase interactions between students and instructors to ensure elevation of learned concepts (from describe to apply).

4 | CONCLUSIONS

In agricultural education, teachers and instructors must pursue the inclusion of multidisciplinary and interdisciplinary programs. These concepts can be primed by systems thinking approaches and experiential learning. The development of such programs is pivotal for the training and success of future leaders and decision makers. The transformation that this course has undergone can serve as an example of accessible and flexible teaching during the COVID-19 pandemic that allowed increased independent learning while maintaining focus on problem-solving. Its success is documented with the evaluations and assessments taken by the students during the transformative periods. The lessons learned during and after the COVID-19 pandemic will help to improve course delivery in the future and include the following:

- Students value in person learning more than online learning and perceive greater interactions with instructors and greater elevation of learning (even though the instructors observed the opposite) when course discussion was held in person in 2022.
- Student learning and interaction increased when conducted in smaller groups as was necessitated during the COVID-19 pandemic dedensification.
- Students' appreciation of course reading and other materials decreased when in-person lecture is provided (even though the lecture was not intended to support content learning but rather support application of content).
- High standards for teaching and learning that emphasize problem-solving and systems thinking can be maintained when meeting time is reduced.

AUTHOR CONTRIBUTIONS

Osler Ortez: Conceptualization; methodology; project administration; visualization; writing—original draft;

writing—review and editing. **Alyssa Hall**: Conceptualization; methodology; writing—original draft; writing—review and editing. **Meghan Sindelar**: Conceptualization; methodology; project administration; visualization; writing—original draft; writing—review and editing.

ACKNOWLEDGMENTS

The authors would like to thank the students taking the course during their years of study for completing the evaluations and learning assessments. Authors also would like to thank instructors involved in the course in past years. The project was approved as exempt by the University of Nebraska-Lincoln's Institutional Review Board (IRB), project ID 20805.

Open Access funding enabled and organized by Projekt DEAL.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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REFERENCES

Al-Balas, M., Al-Balas, H. I., Jaber, H M., Obeidat, K., Al-Balas, H., Aborajooh, E A., Al-Taher, R., & Al-Balas, B. (2020). Distance learning in clinical medical education amid COVID-19 pandemic in jordan: Current situation, challenges, and perspectives. *BMC Medical Education*, *20*, 341. https://doi.org/10.1186/s12909-020-02257-4

Arias, J. J., & Walker, D M. (2004). Additional evidence on the relationship between class size and student performance. *Journal of Economic Education*, *35*(4), 311–329. https://doi.org/10.3200/JECE.35.4.311-329

Anderson, Z D., Hargiss, C L. M., & Norland, J E. (2022). Skill development using interdisciplinary problem solving in a natural resources capstone course. *Natural Sciences Education*, *51*, e20078. https://doi.org/10.1002/nse2.20078

Baticulon, R E., Sy, J. J., Alberto, N R I., Baron, M B C., Mabulay, R E C., Rizada, L G T., Tiu, C J S., Clarion, C A., & Reyes, J C B. (2021). Barriers to online learning in the time of COVID-19: A national survey of medical students in the philippines. *Medical Science Educator*, *31*, 615–626. https://doi.org/10.1007/s40670-021-01231-z

Bawden, R. J. (1983). Experiential learning in agriculture. *Training for agriculture and rural development*. FAO.

Bawden, R J., Macadam, R D., Packham, R J., & Valentine, I. (1984). Systems thinking and practices in the education of agriculturalists. *Agricultural Systems*, *13*(4), 205–225. https://doi.org/10.1016/0308-521X(84)90074-X

Bergmann, J., & Sams, A. (2012). *Flip your Classroom: How to reach every student in every class every day*. International Society for Technology in Education.

Brevik, E C., Krzic, M., Muggler, C., Field, D., Hannam, J., & Uchida, Y. (2022). Soil science education: A multinational look at current perspectives. *Natural Sciences Education*, *51*, e20077. https://doi.org/10.1002/nse2.20077

Brown, S., Krzic, & M. (2021). Lessons learned teaching during the COVID-19 pandemic: Incorporating change for future large science courses. *Natural Sciences Education*, *50*, e20047. https://doi.org/10.1002/nse2.20047

Burke, A. S., & Fedorek, B. (2017). Does "flipping" promote engagement: A comparison of traditional, online, and flipped class. *Active Learning in Higher Education*, *18*(1), 11–24. https://doi.org/10.1177/1469787417693487

Cloud, J. P. (2006). Some systems thinking concepts for environmental educators during the decade for education for sustainable development. *Applied Environmental Education & Communication*, *4*(3), 225–228.

Cutri, R. M., & Mena, J. (2020). A critical reconceptualization of faculty readiness for online teaching. *Distance Education*, *41*(3): 361–380. https://doi.org/10.1080/01587919.2020.1763167

Dale, A., & Newman, L. (2005). Sustainable development, education and literacy. *International Journal of Sustainability in Higher Education*, *6*(4), 351–362. https://doi.org/10.1108/14676370510623847

Ehrenberg, R G., Brewer, D J., Gamoran, A., & Willms, J. D (2001). Class size and student achievement. *Psychological Science in the Public Interest*, *2*(1), 1–30. https://doi.org/10.1111/1529-1006.003

Ellis, G., & Weekes, T. (2008). Making sustainability 'real': Using group-enquiry to promote education for sustainable development. *Environmental Education Research*, *14*(4), 482–500. https://doi.org/10.1080/13504620802308287

Ginzburg, A L., Check, C E., Hovekamp, D P., Sillin, A N., Brett, J., Eshelman, H., & Hutchison, J E. (2019). Experiential learning to promote systems thinking in chemistry: evaluating and designing sustainable products in a polymer immersion lab, *Journal of Chemical Education*, *96*(12), 2863–2871. https://doi.org/10.1021/acs.jchemed.9b00336

Hiller Connell, K. Y., Remington, S. M., & Armstrong, C. M. (2012). Assessing systems thinking skills in two undergraduate sustainability courses: A comparison of teaching strategies. *Journal of Sustainability Education*, *3*. https://krex.k-state.edu/dspace/bitstream/handle/2097/13783/Assessing%20systems%20-%20publisher%27s%20PDF.pdf?sequence=1&isAllowed=y

Holling, C. S. (2001). Understanding the complexity of economic, ecological, and social systems. *Ecosystem*, *4*, 390–405. https://doi.org/10.1007/s10021-001-0101-5

Hung, W. (2008). Enhancing systems-thinking skills with modeling. *British Journal of Educational Technology*, *39*(6), 1099–1120. https://doi.org/10.1111/j.1467-8535.2007.00791.x

Jacobson, M J., & Wilensky, U. (2006). Complex systems in education: Scientific and educational importance and implications for the learning sciences. *Journal of the Learning Sciences*, *15*(1): 11–34. https://doi.org/10.1207/s15327809jls1501_4

International Plant Nutrition Institute (IPNI). (2022). *4R plant nutrition manual: A manual for improving the management of plant nutrition*. http://www.ipni.net/article/IPNI-3255

Keck, M., Mamo, M., Sindelar, M., Speth, C., & Brown, S. (2021). Student perception of engagement and learning in a flipped soil nutrient management course management course. *NACTA Journal*, *65*, 368–374. https://www.nactateachers.org/index.php/volume-65-november-2020-october-2021/3165-student-perception-of-engagement-and-learning-in-a-flipped-soil-nutrient-management-course

Kolb, D. A. (2014). *Experiential learning: Experience as the source of learning and development* (2nd ed.). Pearson Education.

https://www.pearson.com/us/higher-education/program/Kolb-Experiential-Learning-Experience-as-the-Source-of-Learning-and-Development-2nd-Edition/PGM183903.html

Martin, S. (2008). Sustainable development, systems thinking and professional practice. *Journal of Education of Sustainable Development*, *2*, 31–40. https://doi.org/10.1177/097340820800200109

Mckim, A J., Sorensen, T J., & Burrows, M. (2021). The COVID-19 pandemic and agricultural education: An exploration of challenges faced by teachers. *Natural Sciences Education*, *50*, e20060. https://doi.org/10.1002/nse2.20060

Mennin, S. (2010). Self-organization, integration and curriculum in the complex world of medical education. *Medical Education*, *44*, 20–30. https://doi.org/10.1111/j.1365-2923.2009.03548.x

Millea, M., Wills, R., Elder, A., & Molina, D. (2018). What matters in college student success? Determinants of college retention and graduation rates. *Education*, *138*(4), 309–322. https://eric.ed.gov/?id=EJ1180297

Monroe, M C., Plate, R R., & Colley, L. (2015). Assessing an introduction to systems thinking. *Natural Sciences Education*, *44*, 11–17. https://doi.org/10.4195/nse2014.08.0017

Moorhouse, B. L., & Tiet, My C. (2021). Attention to implement a pedagogy of care during the disruptions to teacher education caused by COVID-19: A collaborative self-study. *Studying Teacher Education*, *17*(2):208–227. https://doi.org/10.1080/17425964.2021.1925644

Moravec, M., Williams, A., Aguilar-Roca, N., & O'dowd, D K. (2010). Learn before lecture: A strategy that improves learning outcomes in a large introductory biology class. *CBE-Life Sciences Education*, *9*, 473–481. https://doi.org/10.1187/cbe.10-04-0063

O'Flaherty, J., & Phillips, C. (2015). The use of flipped classrooms in higher education: A scoping review. *The Internet and Higher Education*, *25*, 85–95. https://doi.Org/10.1016/j.iheduc.2015.02.002

Radunovich, H. L., & Acharya, S. (2018). If you flip it, will they watch? case evaluation of a hybrid course. *NACTA Journal*, *62*, 84–88. https://www.jstore.org/stable/10.2307/90021577

Riess, W., & Mischo, C. (2010). Promoting systems thinking through biology lessons. *International Journal of Science Education*, *32*, 705–725. https://doi.org/10.1080/09500690902769946

Runck, B. C., Brakke, M P., & Porter, P M. (2015). The extended classroom framework for teaching systems analysis of food systems. *Natural Sciences Education*, *44*, 101–111. https://doi.org/10.4195/nse2015.04.0004

Sindelar, M., Ortez, O., & Kuhn, A. (2022). *Flipped course design allows flexibility in meeting student needs during Covid-19*. North American Colleges and Teachers of Agriculture. https://www.nactateachers.org/images/TeachingTips/2022/37_TT_-_Sindelar.pdf

Tang, T., Abuhmaid, A M., Olaimat, M., Oudat, D M., Aldhaeebi, M., & Bamanger, E. (2020). Efficiency of flipped classroom with online-based teaching under COVID-19, Interactive Learning Environments. *Interactive Learning Environments*, *31*, 1077–1088. https://doi.org/10.1080/10494820.2020.1817761

UNESCO. (2020). *Education: From disruption to recovery*. UNESCO. https://en.unesco.org/covid19/educationresponse/

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology*, *24*, 535–585. https://doi.org/10.1016/0010-0285(92)90018-W

Walker, K. A., & Koralesky, K. E. (2021). Student and instructor perceptions of engagement after the rapid online transition of teaching due to COVID-19. *Natural Sciences Education*, *50*, e20038. https://doi.org/10.1002/nse2.20038

Wiek, A., Withycombe, L., Redman, C., & Mills, S. B. (2011). Moving forward on competence in sustainability research and problem solving. *Environment Magazine*, *53*(2), 3–12.

Wilson, K. (2020). Balancing the disruptions to the teaching and learning equilibrium-responsive pedagogic approaches to teaching online during the Covid-19 pandemic in general chemistry classes at an arabian gulf university. *Journal of Chemical Education*, *97*, 2895–2898. https://doi.org/10.1021/acs.jchemed.0c00702

How to cite this article: Ortez, O., Hall, A., & Sindelar, M. (2023). Refined teaching methods, systems thinking, and experiential approaches enhanced students learning through COVID-19. *Natural Sciences Education*, *52,* e20101. https://doi.org/10.1002/nse2.20101