Complementary teaching approaches facilitating interdisciplinary soil science education

Authors: Brown, Sandra, Fu, Guopeng, and White, Lisa W.

Source: Canadian Journal of Soil Science, 102(2) : 433-443

Published By: Canadian Science Publishing

URL: https://doi.org/10.1139/CJSS-2021-0096

ARTICLE

Complementary teaching approaches facilitating interdisciplinary soil science education

Sandra Brown, Guopeng Fu, and Lisa W. White

Abstract: The complementary nature of different teaching approaches in facilitating student learning is rarely discussed in the literature. This study compared diverse teaching approaches in soil science education to explore how a combination of instructional approaches can support student learning. Student perspectives on lectures, problem-based learning, and experiential learning in three upper-level university soil science courses were assessed through student enrolment data and survey responses. Results emphasize the benefits of integrating theory and practice and support the integration of concepts from soil physics, chemistry, and biology within individual courses. All respondents who took two or more courses indicated that the distinct teaching approaches and the integration of soil physics, chemistry, and biology within individual courses were beneficial to their learning. Lectures and problem-based learning were seen as pedagogically reciprocal, with theory supporting the application of knowledge for 75% students, while others noted that having the management course first provided context for learning additional theory. A subset of students (n = 9) indicated the relevance of the interdisciplinary nature of the courses for their current employment. Our findings suggest that combining knowledge-based and competency-based approaches may support both student learning and workforce demands and that diverse teaching approaches can work together to support student learning. The research outcomes call for fellow instructors to diverge from the dichotomy of passive and active learning and to consider the complementary nature of distinct teaching strategies.

Key words: problem-based learning, active learning, soil science education, interdisciplinary.

Résumé : La littérature parle rarement de la complémentarité des diverses méthodes pédagogiques qui facilitent l'apprentissage. Les auteurs ont comparé différentes approches à l'enseignement de la science du sol pour déterminer comment plusieurs techniques d'instruction, combinées, peuvent aider l'étudiant à apprendre. Ils ont évalué le point de vue de l'étudiant sur les exposés didactiques, la résolution de problèmes et l'apprentissage par l'expérimentation dans trois cours universitaires supérieurs en pédologie d'après les inscriptions aux cours et les réponses d'un sondage. Les résultats illustrent les avantages que présente l'intégration de la théorie et de la pratique, et appuie l'intégration des principes de la physique, de la chimie et de la biologie des sols aux cours. Les répondants qui s'étaient inscrits à deux cours ou davantage ont tous mentionné que les méthodes d'enseignement distinctes et l'intégration de la physique, de la chimie et de la biologie du sol au cours les avaient aidés dans leur apprentissage. Sur le plan pédagogique, on estime que les exposés didactiques et la résolution de problèmes ont un effet similaire, les bases théoriques favorisant l'application des connaissances pour 75 % des étudiants, alors que le reste estime qu'en suivant d'abord le cours de gestion, ils acquièrent les fondements nécessaires mieux assimiler la théorie. Un sous-groupe (n = 9) a mentionné la pertinence de l'interdisciplinarité des cours en regard de leur emploi actuel. D'après leurs constatations, les auteurs estiment qu'en combinant les approches qui reposent sur le savoir et celles qui s'appuient sur les compétences, on répondrait à la fois au désir d'apprendre des étudiants et à la demande de main-d'œuvre. Les différentes approches pédagogiques peuvent se marier pour faciliter l'apprentissage. Les résultats de ces travaux préconisent que les instructeurs laissent de côté la dichotomie de l'apprentissage passif et actif pour envisager la complémentarité des stratégies d'enseignement distinctes. [Traduit par la Rédaction]

Mots-clés : apprentissage par résolution de problèmes, apprentissage actif, enseignement de la science du sol, interdisciplinarité.

Received 23 July 2021. Accepted 22 September 2021.

S. Brown. Faculty of Land and Food Systems, University of British Columbia, Vancouver, V6T 1Z4 Canada.

G. Fu. College of Teacher Education, East China Normal University, Shanghai, People's Republic of China.

L.W. White. Institute for the Scholarship of Teaching and Learning (ISoTL), University of British Columbia, Vancouver, V6T 1Z1, Canada.

Corresponding author: Sandra Brown (email: sandra.brown@ubc.ca).

Introduction

Soil, a largely nonrenewable resource, supports numerous environmental and societal functions including biomass production, nutrient and water cycling, and belowground biodiversity (Blum 2005). Given the importance of soils in supporting ecosystem services, soil science contributes disciplinary knowledge to understanding societal challenges such as food and water security, sustainable land management, and climate change (Bouma 2014; Paustian et al. 2016; Smith et al. 2020). The integrated nature of soil science, encompassing the lithosphere, biosphere, and hydrosphere, uniquely situates soil scientists to confront complex problems (Keesstra et al. 2016). However, addressing these challenges calls for soil science education that has progressed beyond a focus on agriculture and agronomy to encompass fields such as forestry, ecology, hydrology, geology, and environmental sciences (Hartemink et al. 2008).

Despite the inherently interdisciplinary nature of soils, soil science education has traditionally been structured around the subdisciplines of soil physics, soil chemistry, and soil biology (Hopmans 2007). This approach, however, may not facilitate an understanding of the complex nature of soil systems. Baveye et al. (2006) stressed the need for soil science education to take a problem-solving approach and incorporate different disciplinary perspectives. Havlin et al. (2010) recommended teaching strategies that supported interdisciplinarity and were career-oriented. The interdisciplinary aspect was also identified in soil science education in Canada, where soil science courses were often required by nonagricultural majors such as geology, environmental science, geography, biology, and environmental chemistry (Diochon et al. 2017). Increasingly students with a background in soil science have gone on to work in diverse fields such as forestry, reclamation, and urban land management (Baveye et al. 2006; Field et al. 2017). However, employers identified that recent graduates had limited field experience, data interpretation skills, problem-solving skills, and knowledge of soil processes (Havlin et al. 2010; Masse et al. 2019).

The debate around knowledge-based versus competency-based approaches in education has engaged researchers from around the globe (e.g., Kosaki et al. 2020; Fu 2020). Such debate is often extended to controversies around active versus passive learning strategies and integration versus differentiation of disciplines (Young and Muller 2010). In science education, constructivism has been a key research methodology in framing learning since the 1980s (Taber 2006). This theoretical framework asserts that students construct knowledge based on their experiences as a learner and has informed a wide range of teaching and learning approaches such as inquiry-based (Fosnot 1989) and problem-based learning (PBL) (Savery and Duffy 1995). Correspondingly, a paradigm shift, which attempts to end the prevalence of the lecture and produce more student-centered learning in higher education, has been ongoing since the 1990s (Barr and Tagg 1995). The meta-analysis of Freeman et al. (2014) indicated that active learning improved exam scores and reduced failure rates. However, Kirschner et al. (2006) reviewed empirical research and argued that minimal guidance instruction is less effective than direct instruction for novice learners. Roehling et al. (2017) evaluated test performance between traditional and flipped classrooms in an introductory psychology course and found that students with lower overall grade point averages had lower performance on flipped class topics.

Instructors of introductory soil science courses in the United States report diverse teaching approaches, with 44% of course hours dedicated to active learning, peer learning, flipped classroom, and online learning. Despite this shift toward more student-centered approaches, 56% of course hours were taught using a standard lecture format, with 92% of institutions reporting a laboratory component (Jelinski et al. 2019). A survey of introductory soil science course instructors within Canada found similar results, with the majority of instructors utilizing traditional lecture (85%) and laboratory (76%) delivery formats (Krzic et al. 2018).

Broad-scale uptake of student-centered approaches at the program level may be limited, but active teaching and learning approaches have been adopted within individual soil science courses. Fieldwork, data interpretation, and PBL are examples of student-centered pedagogies employed in soil science. Yates and Hodgson (2018) incorporated professional learning experiences in a field-based soil science course, providing students with the opportunity to apply soil science skills and knowledge in the context of the profession most relevant to their area of study. Student surveys indicated that professional learning experiences with government, academia, and industry increased their interest in a related area of study and generally met their expectations of what a related career would be like. PBL has been employed in both introductory and upper-level soil science courses (e.g., Strivelli et al. 2011; Amador 2019). Hybrid PBL and team-based learning have been used by Krzic et al. (2020) to provide experiential learning opportunities for upper-level students to connect with practicing professionals and community partners in addressing real-world problems. Results suggested that student engagement was enhanced through real-world case studies and the incorporation of fieldwork and that students gained both soil science knowledge and soft skills (problem solving, team work, and communication). While the importance of experiential and team-based learning has been stressed (e.g., Smiles et al. 2000; David and Bell 2018), little is known about the complementarity of different teaching strategies even though the benefits and drawbacks of active and passive learning strategies have been thoroughly discussed in the literature (e.g., Hake 1998; Berrett 2012; Baeten et al. 2013).

This study explores the complementary nature of three different teaching approaches in facilitating soil science students' learning of interdisciplinary content. The three teaching approaches investigated are lecturing, PBL, and experiential learning in field and laboratory settings. Each teaching approach is featured in one of three, fourth-year soil science courses at a research-intensive university in western Canada. This article contributes to the literature by discussing the challenges and benefits of applying multiple teaching strategies in a soil science program.

Materials and Methods

Research context

In the late 1990s and early 2000s, the Faculty of Agricultural Sciences at the University of British Columbia (UBC) underwent a reorganization. As part of this restructuring, the Faculty adopted an agro-ecological framework, embraced problem-based learning, and rebranded as the Faculty of Land and Food Systems. During this transition, the soil science curriculum was also restructured in part due to declining enrolment and a reduction in the number of faculty members in the soil science group. Soil Science was placed within an agro-ecological framework, and the number of courses offered was reduced due to limited human resources. The upper-level soil sciences courses APBI 401, 402, and 403 were deliberately designed to take an integrative approach, shifting away from sub-disciplinary courses such as soil genesis, soil physics, soil chemistry, and soil biology (which had been previously offered). The curricula in these three upper-level soil science courses take an interdisciplinary approach, drawing from the sub-disciplines to provide a more comprehensive understanding of soil as a system (Klein 2005).

For the past 15 yr, the Applied Biology (ABPI) program at UBC has offered this package of three upper-level soil science courses, taught using three distinct instructional approaches (Table 1). "APBI 401 – Soil Processes" is a lecture-heavy theory course, which provides students with an understanding of the essential physical, chemical, and biology processes that take place in soils. "APBI 402 – Sustainable Soil Management" is a PBL course where students apply their fundamental soil science knowledge to real-world cases in the sustainable management of forested, agricultural, urban, or constructed ecosystems. "APBI 403 – Soil Sampling, Analyses and Data Interpretation" is a hands-on techniques course where students are engaged in field sampling, laboratory analysis, data analysis, and data interpretation. The class sizes of each course range from 35 to 45 students. Although the courses are not required to be taken as a package, nor are they prerequisites of one another, and they can be taken in any order, these restricted elective courses are meant to complement each other and enhance student learning. Our study was conducted with students who had taken one or more of these three courses.

Table 1. Teaching approaches used in the upper-level soil science courses studied.

Course code	Title	Teaching approach
APBI 401	Soil Processes	Lecture
APBI 402	Sustainable Soil Management	Problem-based learning
APBI 403	Soil Sampling, Analyses, and Data Interpretation	Experiential learning

Evaluation

Our study aimed to explore how different teaching approaches work together to support student learning in soil science education. Specifically, we (*i*) explored student academic attributes and registration patterns in three, upper-level soil science courses over the past 15 yr; and (*ii*) assessed student perspectives on how complementary teaching approaches support or hinder their learning in an interdisciplinary setting and their future career.

A two-phase, descriptive, sequential approach to data collection and analysis was employed (Leavy 2017), focusing on historical student enrolment data analysis, followed by the collection and analysis of survey data. A sequential phase-by-phase method enabled us to understand student characteristics and enrolments in relation to the package of courses and then build on this foundation with student perspectives on the courses through survey feedback.

In phase I, student academic characteristics and registration patterns in the three courses (APBI 401, 402, and 403) were examined for the 2003/04 to 2017/18 academic years, the entirety of time this combination of courses had been offered. Student enrolment data was downloaded from the institutional student data system and analyzed according to four sub-questions posed for this portion of research:

(*i*) What proportion of students enrolled in one, two, or three of the three courses?
(*ii*) In what order do we typically see students enrol in the package of three courses?
(*iii*) From which major are students taking one or more of the courses?
(*iv*) Do we see an increase in grades of those students who enrolled in all three of the soil science courses in the package?

The second phase involved the development and implementation of a web-based survey to the population

Table 2. Student survey response rates.

No. courses taken	n	No. participants	Response rate
1	125	39	31%
2	51	20	39%
3	20	16	80%
Total	196	75	38%

of students who had enrolled in at least one course in the package of three upper-level soil science courses between 2013/14 and 2017/18 academic years (n = 196). Note that this included both students still enrolled in the program and recent graduates. The survey questions were developed in Qualtrics© and all surveys were administered from August to October 2018. Pertinent demographic information was requested; however, personal data not deemed relevant to the research question or phenomenon of interest, such as gender and age, were not collected. Six primary demographic questions were posed that enabled researchers to analyze data by specific characteristics such as the number of courses in the complementary package completed (1–3 courses), program of study, year of study, graduation status, and current employment status if graduated. Based on the number of APBI courses undertaken in the package, students were redirected in the web survey to a section of questions relevant to their experience with the courses. For those who had enrolled in two or three courses, six closed-ended and seven open-ended questions were posed. The intent of this survey was to elicit student perspectives and recommendations on if and how the combination of courses (theory and application) benefited their learning; if and how the distinct teaching approaches were beneficial for their learning; if and how the integration of concepts from soil physics, soil chemistry, and soil biology (within each course) was beneficial; and the most beneficial sequence of the courses.

At the survey deadline date, a response rate of 38% (n = 75) was garnered (Table 2). Of those who took three courses (n = 20), 80% responded to our survey, while of those who took two courses (n = 51), 39% responded.

Using Microsoft Office, Excel, and the Statistical Product and Service Solutions (SPSS), survey data were analyzed specifically focusing on the program outcomes and perspectives of participants who had enrolled in two or more of any combination of the three complementary courses. As the basis of this study was to grasp the utility of the combination of the three courses, responses from participants who had enrolled solely in one of the courses in the package were not analyzed beyond their reasons for not registering in the other two complementary courses and the likelihood of enrolling in a second or third course in this package in the future. Both the frequency of responses and comments from students with respect to theory and its application, interdisciplinary content, and the complementarity of teaching approaches were reported.

Results

From the 2003/04 to 2017/18 academic years, 523 discrete students enrolled in one or more of the courses in the package. "APBI 401 – Soil Processes", the lecture-based theory course, was enrolled in most often by survey participants (Table 3) and was the first course taken in the package 55% of the time. "APBI 402 – Sustainable Soil Management", the PBL course, was the first course taken by 35% of respondents. Factors influencing a student's decision to undertake a second and (or) third course were based on interest in the topic (n = 29), previous experience in soil science courses (n = 25) and (or) with course instructors (n = 25), and interest in applying soil science knowledge (n = 21). Scheduling issues (n = 42) were cited as the main reason students did not take an additional course (Table 4). This suggests that, for these students, instructor, pedagogical approach, and curriculum all played a primary role in return students.

Theory and application

The most repeated comment from participants of the survey centered on the benefits of having an integration of theory and practice. Of the respondents who took two or more courses, 88% indicated that the combination of theory and application was beneficial to their learning (Fig. 1*a*). Students found this package of courses "immersive" and "creat[ed] a comprehensive understanding" of soil science. One student in particular indicated how "the theory helped me understand the why behind the application."

Most respondents who had taken two or more courses (75%) suggested the courses be taken in sequence: "the progression from 401 to 402 to 403 equips students with the theory they need, and then allows them to apply it theoretically and practically," that "you can build upon your knowledge." However, other students (Fig. 1*b*) indicated that by taking an applied course first, they were stimulated to take theory and that having the application prior to theory was beneficial to their learning.

> "Personally, I chose 402 [PBL] because I was most interested in that course which made me more interested in other aspects of soil."

> "I felt I absorbed more in 401 [theory] since I had already taken 402 [PBL]. If I took 401 first, I think I likely would have struggled… having no real-life situations to relate the lectures to."

Table 3. Course enrolment (number of students) and order in which courses were taken.

No. courses taken	First course taken: 401 (lecture)	402 (problem-based)	403 (field and lab)	Other*	Total	
1 course	180	150	26	—	356	(68%)
2 courses	86	27	13	—	126	(24%)
3 courses	23	7	—	11	41	(8%)
Total	289 (55%)	184 (35%)	39 (8%)	11 (2%)	523	(100%)

*Two courses taken simultaneously.

Table 4. Student rationale for course selection.

Category	Response*	1 course (n = 39) No. responses	2 courses (n = 20) No. responses	3 courses (n = 16) No. responses	2 or more courses (n = 36) No. responses	%
Rationale for selecting the first course	Interest in topic	28	18	14	32	89
	Restricted elective in my major	17	10	8	18	50
	Interest in getting additional theory	11	8	8	16	44
	Recommended by a fellow student	6	5	1	6	17
Factors influencing students to take a second or third course	Interest in topic		14	15	29	81
	Previous experience in APBI soil science courses		10	15	25	69
	Previous experiences with course instructors		10	15	25	69
	Interest in applying soil science knowledge		12	9	21	58
	Interest in gaining hands-on field or lab experience		0	12	12	33
Why student did not take a second or third course	Schedule conflict	22	9			
	Course was not offered in the year I wanted to take it	5	6			

*Top responses by category and No. of courses taken. Respondents could choose as many categories as applied.

Thus, while taking courses in sequence may be beneficial for many students, flexibility was seen as important to engage diverse learners.

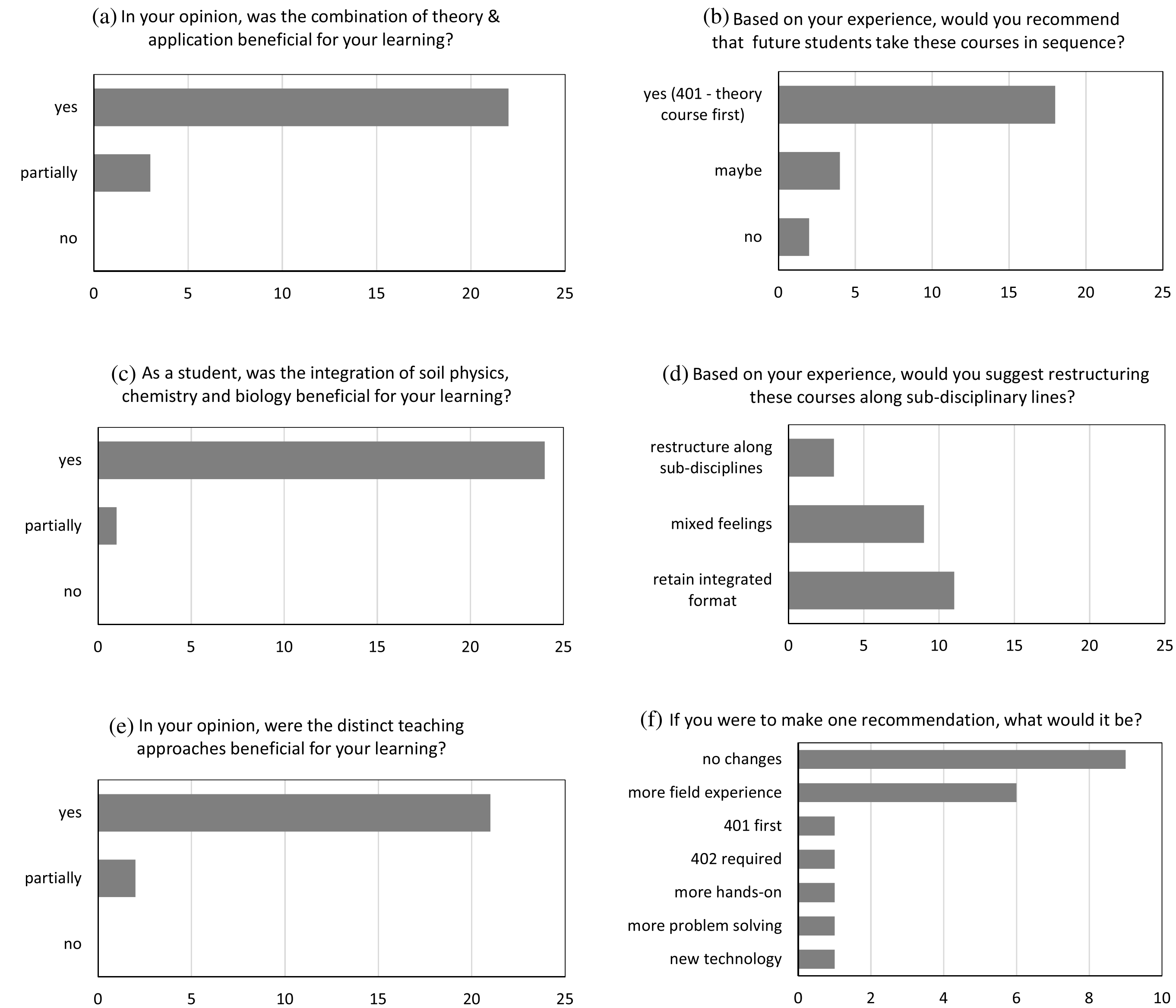
Interdisciplinary content

Each of the three, upper-level soil science courses in this study utilized a modular format, progressing through soil physics, soil chemistry, and soil biology, followed by their integration. Of the respondents who took two or more courses, 96% indicated that the inclusion of concepts from soil physics, chemistry, and biology within individual courses was beneficial to their learning (Fig. 1*c*). As one student stated — "It was beneficial that the concepts were taught separately and then shown how they work together in a more complex system." Another student observed the following:

> "Different students have different strengths with the various concepts of soil science so it's great to be able to execute our strengths and grow areas that need work. We wouldn't get this if only one concept of soil science was looked at."

One respondent synthesized the relevance of interdisciplinary content stating "This integration is crucial to understanding soil as a system." Student reflections support that the PBL and experiential learning courses threaded disciplinary soil science content and helped students see the connections between theory and practice. After examining concepts in these three courses, several students (n = 6) specifically stressed the importance of understanding soil science as a complex system, rather than an independent subject. In addition, the

Fig. 1. Student perspectives on pedagogical approach (based on survey responses from students who had enrolled in two or more courses).



interdisciplinary content appeared to cater to students' varied learning needs and facilitate their growth professionally.

Roughly half of the respondents supported the current, integrated structure of the three courses, while several students noted the potential for restructuring courses along sub-disciplinary lines (Fig. 1*d*). However, students who acknowledged the benefits of both models raised the concern that an understanding of the interconnectedness of concepts may be lost if courses were taught as individual subdisciplines only. One student suggested "having classes that focused on particular topics within the field, while at the same time providing more opportunities for practical application of learnt material." Overall, respondents favored the integration of concepts within courses, while recognizing the potential for greater depth offered by sub-disciplinary courses.

Complementarity of teaching approaches

A distinct pedagogical approach was taken in each of the three courses: lecture, PBL, and experiential learning. Of the respondents who took two or more courses, 92% indicated that these distinct teaching approaches were beneficial to their learning (Fig. 1*e*). Comments from past students illustrated this complementarity:

> "I found that having the lecture, problem-based, and lab course was beneficial because they each gave a different way of understanding soil science concepts."

Table 5. Primary focus of program graduates (based on survey responses from students who had enrolled in two or more courses).

Working in a career (n = 14)	Enrolled in another program (n = 7)	Working but not in preferred career (n = 6)
Biologist	M.Sc. (n = 5)	No data
Crop consultant (n = 2)	Professional Masters (n = 2)	—
Environmental consultant	—	—
Farm manager	—	—
Farmer (n = 3)	—	—
Greenhouse manager	—	—
Growing cannabis	—	—
Growing and processing hops	—	—
Inspector, CFIA	—	—
Teacher	—	—
Quality insurance coordinator	—	—

> "I enjoyed the teaching approaches of all 3 courses. It was done so in a way where you just don't rely on memorization but actually using your head to think and problem solve."

> "The mixture of lecture, problem based and hands on help to really develop your understanding of the subject."

One student, however, stated that "mixing the teaching approaches within one course would also work. For example, having labs related to … theory during the 401 course, or more lectures during 402." Overwhelmingly, however, respondents supported retaining the distinct teaching approaches. Exposure to multiple teaching strategies appears to enhance students' understanding of concepts and reinforce knowledge acquisition. The varied teaching approaches led students to perceive soil science concepts from different angles and perspectives and thus facilitated comprehension of concepts.

Of those respondents who took all three courses (n = 20), a slight increase in grade percentage was noted between the first and second course (mean = 79.6, standard deviation = 8.3 vs mean = 81.6, standard deviation = 7.1; n = 232, t = −1.96, p = 0.052). These results suggest that the addition of a second course in the package may only marginally impact student learning. Despite limited impact on test scores, students perceived that the combination of theory and application, of multiple teaching approaches (lecture, PBL, and experiential learning), and the integration of soil physics, chemistry, and biology within each course were beneficial to their learning (Figs. 1*a*, 1*c*, and 1*e*). Students considered a reciprocal relation between the pedagogical approaches of lecturing and PBL, as reflected in comments such as:

> "I am more of a tactile learner so having the application helped to solidify the theory."

> "The problem-based 402 was extremely conducive to understanding the content. The lecture-heavy 401, I felt was essential and since I took that second, I feel it helped me build on all I learned and experienced in 402."

The lectures helped students extract content knowledge from experience and thus transcended students' learning experience in laboratory and field settings. Multiple teaching approaches also catered to learner preferences and appear to consolidate learning regardless of the sequence in which courses were taken.

Career relevance

While the student survey did not directly address work and (or) career relevance, 28 of the 36 respondents who had taken two or more of the courses had graduated, and 14 were working in jobs related to their field of study (Table 5). Nine students included unsolicited comments about the relevance of the interdisciplinary content, application of knowledge, and complementary teaching approaches for their current employment.

> "I think to be prepared to work in agriculture, etc., you need a minimum of all these courses and the knowledge and skills that come with them."

> "In my experiences so far working, I think courses that are broader to cover all components (soil physics, chemistry, biology) is better. At work we are never focused on specific components, it is always about the entire system."

> "This course actually contributes greatly to my day to day soil dealings in my current career."

> "I am often referring back to what I learned in these classes."

The comprehensive approach toward soil science, in terms of both content and pedagogy, appeared to facilitate the transition from school to work and students' success in working in related fields. The interdisciplinary and complementary nature of the courses had long-term positive outcomes for our students. Former students who are now professionals in soil science validated our efforts on interdisciplinarity and engaging students through multiple teaching strategies. Their university classroom experience was not only highly relevant to their career but also contributed to their success. The most common recommendations to instructors for these courses were no change, followed by the addition more field-based experiences (Fig. 1*f*).

Discussion

Knowledge-based versus 21st century competence-based education and the subsequent question around direct instruction versus student-centered approaches have been widely discussed in higher education (Voogt and Roblin 2012; Lee and Anderson 2013). Many studies focused on the comparison of the two types of teaching strategies, i.e., how one teaching approach is better or more effective than the other (e.g. Hake 1998; Baeten et al. 2013; Balch 2014), and empirical evidence is found to support both camps (e.g., Klahr and Nigam 2004; Regmi 2012). Scholars have also made efforts to improve teaching strategies within each camp. For example, questioning is proposed as an effective instructional method to enhance lecturing (Campbell and Mayer 2009). Larson and Lovelace (2013) revealed several guidelines for questioning strategies in lecture-based classrooms in tertiary education including generating questions, which stimulate higher-order thinking skills, asking purposeful questions and leaving sufficient wait time for students to answer. Similarly, Hoskinson et al. (2014) proposed three recommendations for a successful student-centered classroom: focus on big ideas and competencies; cultivate productive interactions by way of teamwork; and incorporating metacognition through student reflections. It appears that lecture-based teaching and student-centered strategies have been situated in a competitive rather than a collaborative relationship in the literature. Thus, our study contributes to higher education in terms of presenting lecture-based and student-centered teaching strategies as reciprocal in facilitating student learning in soil science. Our findings suggest that, regardless of the sequence, lecture-based strategies transcended students' hands-on experience and consolidated their understanding of theory. That practical experience, on the other hand, embodied content in lecture-based courses and prepared students for their future career. Such findings resonate with Mayo's (2004) study where he employed case-based instruction to relate course content to real-life scenarios in an introductory psychology course. Mayo also found that the integration of content, process, and application developed students' understanding of course principles and further suggested that educators integrate their own disciplines with other disciplines in order to promote liberal education. Such suggestions echo our efforts on interdisciplinarity in soil science education.

Lee and Anderson (2013) reviewed and reported both strengths and shortcomings of discovery learning and direct instruction and postulated that "learning in problem-solving domains is fundamentally example based" (p. 463). Worked examples, demonstrating how to solve a problem, were found to be effective in both discovery learning and direct instruction, and the authors suggest that a combination of both strategies can take advantage of the strengths of both approaches. Our study provides empirical support for their postulation, as students perceived that multiple teaching approaches enhanced their learning.

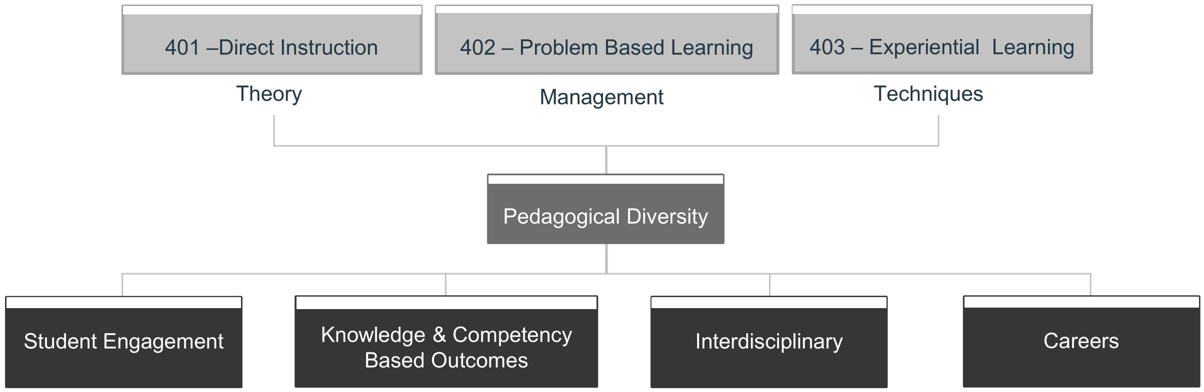
Klein (2005) suggested seven strategies for interdisciplinary teaching in college:

- team teaching and team planning
- clustered and linked courses, learning communities
- interdisciplinary core seminars at introductory and capstone levels
- thematic or problem focus in courses
- proactive attention to integration and synthesis, with process models, theories, and methods from interdisciplinary fields
- collaborative learning in projects and problem-based case studies
- integrative learning portfolios (p. 10)

It appeared that the three advanced soil science courses in our program embodied such strategies. Further, the lecture-based theory course, as evidenced in this study, bolstered PBL approaches and facilitated students' understanding of interdisciplinary content in soil science. Thus, we argue for broader engagement with students in implementing interdisciplinary programs. Lectures and more passive teaching strategies are not standing against interdisciplinary content. On the contrary, lectures provided the theoretical basis for students' PBL and hands-on learning experiences. The Kirschner et al. (2006) study revealed that minimally guided instruction was only advantageous when learners had sufficiently high prior knowledge. Such sufficiently high prior knowledge, they argue, often came from guided instruction. Their research findings provide possible explanations for the effectiveness of combining both lecture-based and active learning strategies in an interdisciplinary setting.

Drawing from global examples of effective practice in soil science education, Field et al. (2020) propose eight soil science teaching principles framed by the intersection of knowledge, practice, learners, and scholarship. These principles recognize soil as a complex system,

Fig. 2. Pedagogical diversity in support of student engagement, learning outcomes, interdisciplinarity, and careers.



the need for diverse teaching environments, and recognize the ability and aspiration of the learner (pp. 194–195). Student perceptions reported in our study align with these principles. Students noted the importance of understanding soil as a system and that diverse teaching approaches facilitated their learning.

As higher education institutions reposition to focus on transferrable skills and competencies and align education with the needs of industry (Fain 2015; Nodine 2016), university programs have adopted learning outcomes, which include problem-solving, critical thinking, and communication and collaboration skills (Berrett 2014). But the inclusion of competencies does not preclude knowledge-based approaches in education. Gosselin et al. (2013) evaluated the development of professional competencies in an environmental studies program and found that the development of competencies can occur concurrently with the development of content knowledge. Gerstein and Friedman (2016) assert that the ideal curriculum provides disciplinary knowledge plus skills. Brevik et al. (2020) point out that finding a balance between knowledge-based and professional skills is particularly important in soil science education at the undergraduate level as graduates go on to careers in a range of fields. Results of our study suggest that a combination of knowledge and competency-based approaches provided graduates with soil science education that was relevant for their careers.

Limitations

The three courses described in this study were developed out of necessity due to faculty retirements and budget constraints, which resulted in fewer faculty members within the department and a need to reduce the number of courses being taught. While the results of this study are supportive of courses that integrate soil physics, chemistry, and biology, the students surveyed had no exposure to alternative course formats. While we endorse integrated courses for teaching soil science fundamentals and their application, we recognize the benefits of specialized courses such as soil ecology, soil fertility, pedology, and soil classification that are taught at institutions with a full complement of soil science faculty.

Student enrolment information from the last 15 yr indicates that only 8% of the students took all three courses and that enrolment in the experiential learning course, "APBI 403 – Soil Sampling, Analyses and Data Interpretation", was low (n = 41) relative to the other two courses. This course is offered in alternate years, limiting the pool of students who took all three courses and the sample size for our analysis. Furthermore, our analytical approach relied on student perceptions and experiences, which we recognize are limited and may not fully reflect the acquisition of knowledge and skills (Deslauriers et al. 2019).

Summary and Conclusions

Soil science education programs increasingly seek to provide graduates with a strong foundation both in soil science principals and in the problem-solving and critical thinking skills sought by employers. Through an assessment of student enrolment data and an online survey of recent soil science graduates, this research explored student perspectives on complementary teaching approaches. Incorporating lectures, PBL, and experiential learning provided pedagogical diversity, which in turn supported broader student engagement and aligned learning with career requirements (Fig. 2). While our results generally support taking theory before applied courses, broader student engagement was achieved when courses could be taken in any order. For most students, theory provided the foundation for application, while for some application provided the context for theory. Furthermore, students perceived that this hybrid approach, incorporating both knowledge-based and competency-based outcomes, facilitated their learning. Soil physics, chemistry, and biology were integrated within each course, reflective of the interdisciplinary nature of soil science. Students expressed the value of this interdisciplinary content in developing systems thinking and understanding soils as a complex system.

Notwithstanding, recent graduates noted the relevance of the interdisciplinary and complementary nature of courses for their current careers.

Acknowledgements

We thank Adriana Briseño-Garzón and the Institute for the Scholarship of Teaching and Learning (ISoTL) at the University of British Columbia for professional support in research design. We recognize Dr. Maja Krzic, Dr. Art Bomke, Dr. Sue Grayston, and all the other instructors who have contributed to the development and teaching of these three courses over the past 15 yr.

Funding

Financial support was provided by the ISoTL Seed program at the University of British Columbia, which funded a scholarship of teaching and learning specialist to work on the project.

Disclosure Statement

No potential competing interests were reported by the authors.

References

Amador, J.A. 2019. Active learning approaches to teaching soil science at the college level. Front. Environ. Sci. **7**: 111. doi:10.3389/fenvs.2019.00111

Baeten, M., Dochy, F., and Struyven, K. 2013. The effects of different learning environments on students' motivation for learning and their achievement: Effects of different learning environments on students' motivation. Br. J. Educ. Psychol. **83**(3): 484–501. doi:10.1111/j.2044-8279.2012.02076.x

Balch, W.R. 2014. A referential communication demonstration versus a lecture-only control: Learning benefits. Teach. Psychol. **41**(3): 213–219. doi:10.1177/0098628314537970

Barr, R.B., and Tagg, J. 1995. From teaching to learning: A new paradigm for undergraduate education. Change **27**(6): 12–25. doi:10.1080/00091383.1995.10544672

Baveye, P., Jacobson, A.R., Allaire, S.E., Tandarich, J.P., and Bryant, R.B. 2006. Wither goes soil science in the United States and Canada? Soil Sci. **171**(7): 501–518. doi:0038-075X/06/17107-501–518

Berrett, D. 2012. How "flipping" the classroom can improve the traditional lecture. Chronicle of Higher Education [Online]. Available from http://chronicle.com/article/How-Flipping-the-Classroom/130857/.

Berrett, D. 2014. Now, everything has a learning outcome. Chronicle of Higher Education [Online]. Available from https://www-chronicle-com.ezproxy.library.ubc.ca/article/Now-Everything-Has-a-Learning/149897/.

Blum, W.E.H. 2005. Functions of soil for society and the environment. Rev. Environ. Sci. Bio/Technol. **4**: 75–79. doi:10.1007/s11157-005-2236-x.

Bouma, J. 2014. Soil science contributions towards sustainable development goals and their implementation: Linking soil functions with ecosystem services. J. Plant Nutr. Soil Sci. **177**: 111–120. doi:10.1002/jpln.201300646.

Brevik, E., Krzic, M., Itkin, D., Uchida, Y., and Cau, H.W. 2020. Guidelines for under- and post-graduate students. Pages 29–46 in T. Kosaki, R. Lal, and L.B. Reyes Sánchez, eds. Soil sciences education: global concepts and teaching. Catena-Schweizerbart, Stuttgart.

Campbell, J., and Mayer, R.E. 2009. Questioning as an instructional method: Does it affect learning from lectures? Appl. Cognit. Psychol. Off. J. Soc. Appl. Res. Mem. Cognit. **23**(6): 747–759. doi:10.1002/acp.1513

David, C., and Bell, M.M. 2018. New challenges for education in agroecology. Agroecol. Sustain. Food Syst. **42**(6): 612–619. doi:10.1080/21683565.2018.1426670

Deslauriers, L., McCarty, L.S., Miller, K., Callaghan, K., and Kestin, G. 2019. Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom. PNAS, **116**(39): 19251–19257. doi:10.1073/pnas.1821936116

Diochon, A., Basiliko, N., Krzic, M., Yates, T.T., Olson, E., Masse, J., et al. 2017. Profiling undergraduate soil science education in Canada: Status and projected trends. Can. J. Soil Sci. **97**(2): 122–132. doi:10.1139/cjss-2016-0058

Fain, P. 2015. Keeping up with Competency. Inside Higher Education [Online]. Available from https://www.insidehighered.com/news/2015/09/10/amid-competency-based-education-boom-meeting-help-colleges-do-it-right

Field, D., Brevik, E., Jirai, H., and Muggler, C. 2020. Guiding the future of soil (science) education: informed by global experiences. Pages 191–198 in T. Kosaki, R. Lal, and L.B. Reyes Sánchez, eds. Soil sciences education: global concepts and teaching. Catena-Schweizerbart, Stuttgart.

Field, D.J., Yates, D., Koppi, A.J., McBratney, A.B., and Jarrett, L. 2017. Framing a modern context of soil science learning and teaching. Geoderma, **289**, 117–123. doi:10.1016/j.geoderma.2016.11.034

Fosnot, C.T. 1989. Enquiring teachers, enquiring learners: A constructivist approach for teaching. Teachers College Press, New York.

Freeman, S., Eddy, S.L., McDonough, M., Smith, M.K., Okoroafor, N., Jordt, H., and Wenderoth, M.P. 2014. Active learning increases student performance in science, engineering, and mathematics. Proc. Nat. Acad. Sci. **111**(23): 8410–8415. doi:10.1073/pnas.1319030111

Fu, G. 2020. The knowledge-based versus student-centred debate on quality education: Controversy in China's curriculum reform. Comp. J. Compar. Int. Educ. **50**(3): 410–427. doi:10.1080/03057925.2018.1523002

Gerstein, M., and Friedman, H.H. 2016. Rethinking higher education: Focusing on skills and competencies. Psychosociol. Iss. Hum. Res. Manag. **4**(2): 104–121. https://ssrn.com/abstract=2783887

Gosselin, D., Cooper, S., Bonnstetter, R.J., and Bonnstetter, B.J. 2013. Exploring the assessment of twenty-first century professional competencies of undergraduate students in environmental studies through a business – Academic partnership. J. Environ. Stud. Sci. **3**: 359–368. doi:10.1007/s13412-014-0164-1

Hake, R.R. 1998. Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. Am. J. Phys. **66**(1): 64–74. doi:10.1119/1.18809

Hartemink, A.E., McBratney, A., and Minasny, B. 2008. Trends in soil science education: Looking beyond the number of students. J. Soil Water Conserv. **63**(3): 76A–83A. doi:10.2489/jswc.63.3.76a

Havlin, J., Balster, N., Chapman, S., Ferris, D., Thompson, T., and Smith, T. 2010. Trends in soil science education and employment. Soil Sci. Soc. Am. J. **74**(5): 1429–1432. doi:10.2136/sssaj2010.0143

Hopmans, J.W. 2007. A plea to reform soil science education. Soil Sci. Soc. Am. J. **71**(3): 639–640. doi:10.2136/sssaj2007.0083l

Hoskinson, A.M., Barger, N.N., and Martin, A.P. 2014. Keys to a successful student-centered classroom: Three recommendations. Bull. Ecolog. Soc. Am. **95**(3): 281–292. doi:10.1890/0012-9623-95.3.281

Jelinski, N.A., Moorberg, C.J., Ransom, M.D., and Bell, J.C. 2019. A survey of introductory soil science courses and curricula in the United States. Nat. Sci. Educ. **48**(1): 1–13. doi:10.4195/nse2018.11.0019

Keesstra, S.D., Bouma, J., Wallinga, J., Tittonell, P., Smith, P., Cerdà, A., et al. 2016. The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals, Soil **2**: 111–128. doi:10.5194/soil-2-111-2016

Kirschner, P.A., Sweller, J., and Clark, R.E. 2006. Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. Educ. Psychol. **41**(2): 75–86. doi:10.1207/s15326985ep4102_1

Klahr, D., and Nigam, M. 2004. The equivalence of learning paths in early science instruction: Effects of direct instruction and discovery learning. Psychol. Sci. **15**(10), 661–667. doi:10.1111/j.0956-7976.2004.00737.x

Klein, J.T. 2005. Integrative learning and interdisciplinary studies. Peer Rev. **7**(4): 8–10. [Online]. Available from https://my.queens.edu/gened/Faculty%20documents/Integrative%20Learning%20Issue-peerReview%202005.pdf

Kosaki, T., Lal, R., and Reyes Sánchez, L.B. (eds). 2020. Soil sciences education: Global concepts and teaching. Catena-Schweizerbart, Stuttgart.

Krzic, M., Brown, S., and Bomke, A.A. 2020. Combining problem-based learning and team-based learning in a sustainable soil management course. Nat. Sci. Educ. **49**(1): 1–11. doi:10.1002/nse2.20008

Krzic, M., Yates, T.T., Basiliko, N., Pare, M.C., Diochon, A., and Swallow, M. 2018. Introductory soil courses: A frontier of soil science education in Canada. Can. J. Soil Sci. **98**(2): 343–356. doi:10.1139/cjss-2018-0006

Larson, L.R., and Lovelace, M.D. 2013. Evaluating the efficacy of questioning strategies in lecture-based classroom environments: Are we asking the right questions? J. Excell. Coll. Teach. **24**(1). ISSN 1052-4800.

Leavy, P. 2017. Research design: Quantitative, qualitative, mixed methods, arts-based, and community-based participatory research approaches. Guilford Press, New York. 300 pp.

Lee, H.S., and Anderson, J.R. 2013. Student learning: What has instruction got to do with it? Ann. Rev. Psychol. **64**: 445–469. doi:10.1146/annurev-psych-113011-143833

Masse, J., Yates, T., Krzic, M., Unc, A., Chen, Z.C., Quideau, S., et al. 2019. Identifying learning outcomes for a Canadian pedology field school: Addressing the gap between new graduates' skills and the needs of the current job market. Can. J. Soil Sci. **99**: 458–471. doi:10.1139/cjss-2019-0040

Mayo, J.A. 2004. Using case-based instruction to bridge the gap between theory and practice in psychology of adjustment. J. Construct. Psychol. **17**(2): 137–146. doi:10.1080/10720530490273917

Nodine, T.R. 2016. How did we get here? A brief history of competency-based higher education in the United States. Competency-based Education, **1**: 5–11. doi:10.1002/cbe2.1004

Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G.P., and Smith, P. 2016. Climate-smart soils. Nature **532**: 49–57. doi:10.1038/nature17174

Regmi, K. 2012. A review of teaching methods–lecturing and facilitation in Higher Education (HE): A summary of the published evidence. J. Effect. Teach. **12**(3), 61–76. [Online]. Available from https://uncw.edu/jet/articles/vol12_3/regmi.pdf.

Roehling, P.V., Root Luna, L.M., Richie, F.J., and Shaughnessy, J.J. 2017. The benefits, drawbacks, and challenges of using the flipped classroom in an introductory to psychology course. Teach. Psychol. **44**(3): 183–192. doi:10.1177/0098628317711282.

Savery, J.R., and Duffy, T.M. 1995. Problem based learning: An instructional model and its constructivist framework. Educ. Technol. **35**(5): 31–38. [Online]. Available from https://www.jstor.org/stable/44428296?seq=1.

Smiles, D.E, White, I., and Smith, C.J. 2000. Soil science education and society. Soil Sci. **165**: 87–97. doi:10.1097/00010694-200001000-00010.

Smith, P., Soussana, J.F., Angers, D., Schipper, L., Chenu, C., Rasse, D.P., et al. 2020. How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal. Global Change Biol., **26**: 219–241. doi:10.111/gcb.14815.

Strivelli, R.A., Krzic, M., Crowley, C., Dyanatkar, S., Bomke, A.A., and Simard, S.W. 2011. Integration of problem-based learning and web-based multimedia to enhance a soil management course. Nat. Sci. Educ. **40**(1): 215–223. doi:10.4195/jnrlse.2010.0032n.

Taber, K.S. 2006. Beyond constructivism: The progressive research programme into learning science. Stud. Sci. Educ. **42**(1): 125–184. doi:10.1080/03057260608560222.

Voogt, J., and Roblin, N.P. 2012. A comparative analysis of international frameworks for 21st century competences: Implications for national curriculum policies. J. Curricul. Stud. **44**(3): 299–321. doi:10.1080/00220272.2012.668938.

Yates, T., and Hodgson, K. 2018. Professional learning experiences in a field-based course: student perceptions and preferences. Nat. Sci. Educ. **47**: 1–10. doi:10.4195/nse2017.12.0024.

Young, M., and Muller, J. 2010. Three Educational Scenarios for the Future: Lessons from the Sociology of Knowledge. Eur. J. Educ. **45**(1): 11–27. doi:10.1111/j.1465-3435.2009.01413.x.