Abstract
A survey of introductory soil science or equivalent (ISS) instructors and courses at 79 institutions differing in land-grant status (38 land-grant, 41 non-land-grant) and Carnegie category (48 doctoral, 16 master’s, 10 baccalaureate, 2 associate, 3 respondents did not identify by Carnegie classification) was conducted to collect information about the current state of ISS course offerings in the United States. Our data demonstrates little evidence for curricular differences between land-grant and non-land-grant institutions. A “depth” ranking of topical components of these courses showed that soil water concepts and soil classification were allotted the most time, on average. Pedagogical styles were diverse, with 44% of ISS course hours dedicated to active learning, flipped classroom, or online learning formats. There was no significant relationship between class size and institution type and the proportion of the non-lab component of the course taught in alternative formats. Over 40% of respondents expressed interest in connecting with other introductory soils instructors to share course materials and explore new approaches. The results of this survey will serve as a resource to (1) improve general knowledge of the diversity of materials, and methods used to teach introductory soil science courses; (2) assist instructors or institutions in the process of revising or reviewing their introductory soil science courses; and (3) identify opportunities for cross-institutional cooperation or development of course materials and resources.

Core Ideas
- Soil water concepts and soil classification were allotted the most time among topical categories.
- Little evidence for curricular differences between land-grant and non-land-grant institutions.
- Pedagogical styles are diverse, with 44% of course hours dedicated to non-traditional approaches.

Introductory soil science or equivalent (ISS) courses represent the major gateway and primary exposure for undergraduate student entry into soil science or closely related fields. Thus, these courses are of significant concern for the academic and professional soil science communities and are often viewed as important indicators for the future of the field. Many previous studies have focused primarily on trends in student numbers in ISS courses and soil science programs (e.g., Baveye et al., 2006; Hartemink et al., 2008; Hartemink and McBratney, 2008; Hansen et al., 2007; Brevik et al., 2014, 2018). These studies have highlighted important differences in ISS trends between institutions of differing land-grant status and Carnegie classification. Despite this focus, few studies have assessed teaching styles and topical content across ISS courses, particularly between institutions of differing Carnegie classification or land-grant status.

There is a strong need for a comprehensive community assessment of teaching styles, topical content, and course statistics in ISS courses across diverse institutions. Furthermore, the continued emergence of high-quality, open-source materials designed to enhance teaching and learning in soil science have a strong potential to revolutionize ISS courses and the ability of instructors to exchange ideas and approaches. A recent study of ISS courses in Canadian institutions documented an increased need for innovative content development and evaluation of teaching methods (Krizic et al., 2018). Because soil science in particular lends itself to teaching through diverse learning and active learning styles (Strivelli et al., 2011; Field et al., 2011), developing novel course materials and approaches is critical to the continued evolution and relevance of these courses.

From 2016 to 2017, we conducted an electronic survey designed to collect information about the current state of ISS courses, teaching approaches, and topical focus from the primary instructors of such courses, primarily in the United States. The three objectives of this study were to: (1) improve knowledge of the diversity of materials, methods, and pedagogies utilized to teach ISS courses in the United States; (2) assist instructors or institutions to identify resources or common community practices in the process.
of revising or reviewing their ISSe courses; and (3) identify opportunities for cross-institutional cooperation or the development of multi-user course materials and resources.

**METHODS**

**Survey Design**

A 68-question online survey was designed and implemented in consultation with the University of Minnesota–Twin Cities Center for Educational Innovation to ensure that it met standards of educational survey design, particularly for online content delivery. The survey was implemented through the University of Minnesota Enterprise version of the Qualtrics survey software platform. Our targeted population of survey respondents was primary instructors of ISSe courses. For the purposes of this survey, we defined ISSe course as the course at an institution that serves as (1) the requisite gateway for students into higher-level soil science courses, or (if there are no higher-level soil science courses offered) (2) the course that contains the greatest focus on fundamental aspects of soil science of any course at an institution.

Of these questions, approximately 3 (4%) were introductory questions regarding survey consent and targeted respondent population; 21 (31%) aimed to understand background information about the institution, instructor, and ISSe course; 9 (13%) aimed to understand student numbers and population in ISSe courses; 21 (31%) aimed to understand topical foci, course delivery, and textbook choices; and 10 (15%) aimed to understand teaching styles and pedagogy. To improve question clarity or identify any missing questions, a preliminary version of the survey was completed by individuals who have previously or currently teach ISSe courses and by each of the authors.

**Respondents**

Respondents were asked to self-report the land-grant classification category of their institution, with land-grant (LG) institutions defined as institutions of higher education in the United States designated by a state to receive the benefits of the Morrill Acts of 1862 and 1890, while non-land-grant (NLG) institutions do not meet these criteria. It is important to note that there are nine Canadian members of the Association of Public and Land-Grant Universities (APLU), which, although these institutions do not receive Morrill Act benefits, may be considered closely aligned in mission and purpose with U.S. land-grant institutions. Two of these Canadian APLU member institutions were respondents in our survey.

Additionally, respondents were asked to self-report the appropriate Carnegie classification of their institution as one of four basic categories, generalized from the basic system of Carnegie classification of institutions of higher learning (Indiana University Center for Postsecondary Research, 2015): Doctoral-Universities (including R1, R2, and R3 categories: doctoral), Masters Colleges and Universities (including M1, M2, and M3 categories: masters), Baccalaureate Colleges (including Arts-Sciences and Diverse Field focus: baccalaureate), and Associate’s Colleges (including all subcategories therein: associate). To provide anonymity, respondents were not required to identify the name of their institution, but were given the option to provide an institutional email address to provide further information if they wished. Sixty-eight percent of respondents chose to enter their email address, allowing for follow-up clarification if necessary.

Potential participants were contacted directly via email first. No comprehensive list of ISSe instructors exists. Therefore, institutions that teach soil science content were identified from a list of colleges with soil science, agronomy, crop science, or environmental science courses and programs from a website maintained by the American Society of Agronomy (ASA), Crop Science Society of America (CSSA), and Soil Science Society of America (SSSA) (ASA-CSA-SSSA, 2018). Websites for each institution were searched first for a listing of a likely ISSe course, and if possible, the instructor of each course. To do so, searches for the keyword “soil” was performed in each institution’s course catalog. Once a potential ISSe course was identified, a search was conducted for the program in which that course was taught, and the instructor of record. If the instructor of record could be identified, then a scripted email message was sent to the instructor requesting their participation. Follow-up emails were sent if no survey response with an email identifying that institution was provided to indicate completion of the survey by the appropriate respondent. In cases where the instructor of record could not be identified, then a scripted email was sent to the administrators (department heads, deans, etc.) expected to have supervision over the target course or instructor. These scripted emails contained a request to forward the email to the appropriate instructor. The list of institutions is likely not comprehensive, and was known to have limited listings of associate degree-granting institutions. Therefore, additional requests were sent as mass emails to members of soils-related professional societies or society divisions. Those included the ASA Undergraduate Education Community, the Ecological Society of America Education Section, the National Association of Geoscience Teachers, the North American Colleges and Teachers of Agriculture, the Society of College Science Teachers, and the SSSA Education and Outreach Division.

Between July 2016 and July 2017, ISSe instructors from 79 institutions responded to the survey; 76 of these institutions were United States institutions of higher education, whereas 3 were respondents from Canadian institutions. A total of 38 of these respondents identified their institutions as U.S. land-grant institutions, whereas 41 respondents did not identify as land-grant institutions. All 38 land-grant institutions identified as doctoral-granting institutions, and of the non-land-grant respondent institutions, 10 were doctoral-granting, 16 were masters-granting, 10 were baccalaureate-granting, and 2 were associate-granting institutions. Three respondents did not identify by Carnegie classification. Of the three Canadian institutions, two considered themselves land-grants and are members of the APLU. For this article, we analyzed the survey data based on both generalized Carnegie classification (doctoral, masters, baccalaureate, associate) and land-grant status (land-grant, non-land-grant). The Canadian respondents were included in the appropriate categories according to their responses.

In a small number of cases, multiple responses were received from the same institution under two different scenarios: (1) the primary instructor completed a partial survey or completed the survey twice, or (2) multiple instructors or teaching assistants completed the survey. In the first case, we only included data from the most complete survey entry as part of the final data. In the second case, we only used data from the primary instructor for questions dealing with student population, course administration, etc., but used the average of all instructors for questions related to topical content, pedagogy, and teaching style.
Data Curation

To address the objectives of this work, several categories of questions were developed for the online survey. A number of questions involved categorical responses, which were compiled and reported in this manuscript as percentages of total respondents, or as percentages of total respondents within a given group. Other questions involved self-reported numerical estimates, such as requesting that respondents estimate the percentage of time throughout the course that a certain pedagogical technique or teaching method was used. The numerical responses to these questions were aggregated in total and by Carnegie and land-grant categories, and are reported as averages with corresponding standard deviations. In some cases, instructor estimates for these numerical responses exceeded 100%. We therefore normalized individual responses to the sum of the estimates, in which case the normalized (and not raw values) were reported. In all cases, this normalization procedure did not result in values that differed by more than 4% of raw values, and in no case did the normalization procedure result in changes to the relative order of final numbers. In some cases for numerical or categorical responses, only a subset of respondents replied. For example, in questions about the laboratory component of the introductory soil science course, only those institutions that offered a laboratory component were able to view the questions and respond. In those cases, responses in each category (in the case of categorical data) or numerical averages (in the case of quantitative data) were reported only for the subset of respondents who answered. The only exception to this was for required and recommended textbook choices, which were reported as a percentage of total respondents to reflect prevalence in the respondent population as a whole.

Fundamentals of Soil Science Topical Categories

To explore the topical content, pedagogical approach, and priority of topics taught in ISSe courses, we condensed the performance objectives of the fundamentals of soil science (FSS) exam (SSSA, 2012) into 36 general topical categories covering much of the breadth of potential ISSe course material. We chose to utilize the FSS exam performance objectives as the basis for forming these 36 topical categories to avoid issues of bias by using topical foci from particular textbooks or existing course syllabi. For each of the 36 generalized topical categories, instructors were asked to report the depth to which each of the topics was taught in their ISSe course on a scale of 1 to 6, where 1 = no time allotted; 2 = mentioned briefly, not explored; 3 = less than half lecture, lab, or discussion; 4 = more than half lecture, lab, or discussion; 5 = one entire lecture, lab or discussion; and 6 = multiple, integrated lectures, labs, or discussions. Additionally, instructors were asked to self-report in which course setting (lecture, laboratory, field, or discussion) each of the 36 generalized topical categories was taught.

Statistical Analysis

Statistical differences between categories of respondent institutions for selected survey questions (those that involved quantitative numerical answers) were detected by Tukey’s Honestly Significant Difference (HSD) tests for pairwise difference between groups following Type II ANOVA analysis. Differences between groups with p values less than a critical value of 0.05 were considered significant, and the null hypothesis that group means were the same was rejected. All statistical analysis was accomplished in R (R Core Team, 2018).

RESULTS

Instructor Title and Background

Among all respondent institutions, 57 (72%) report having a sole primary instructor for the ISSe course. Unfortunately, we cannot determine whether this is a single primary instructor for all course offerings or a single primary instructor for each course offering due to the structure of questions asked. Numbers of reported primary instructors ranged from a single instructor up to six instructors (including all levels of faculty, instructors, or staff involved in leading lecture, laboratory, or field components of the ISSe course). Full professors made up 47% of reported primary instructors for ISSe courses at doctoral institutions (29% of masters, baccalaureate, and associate) and 52% of land-grant institutions (24% for non-land-grants). Associate professors were primary instructors for the ISSe course for 25% of doctoral institutions (35% of masters, baccalaureate, and associate) and 22% of land-grant institutions (32% of non-land-grants). Assistant professors were primary instructors for the ISSe course for 16% of doctoral institutions (32% of masters, baccalaureate, and associate) and 16% of land-grant institutions (26% non-land-grants). Lecturers, adjunct professors, and instructors were primary instructors for ISSe courses for 12% of doctoral institutions (19% of masters, baccalaureate, and associate) and 4% of land-grant institutions (7% non-land-grants). The numbers cited above do not add up to 100% in all cases, because some institutions have multiple instructors, and therefore, multiple responses.

Ninety-two percent of all ISSe instructors held a Ph.D. (96% in doctoral, 83% in masters, 82% in baccalaureate, and 100% in associate institutions), four institutions reported having primary instructors that held an M.S. degree (6%), and one institution reported having a primary instructor that held a B.S. degree (<2%). Ninety-five percent of ISSe instructors at land-grant institutions held a Ph.D. degree, whereas 87% of instructors at non-land-grant institutions held a Ph.D degree.

Across all respondents, 78% of primary instructors had a primary academic background in soil science or a sub-discipline of soil science, whereas 22% of instructors had an academic background in a closely related field such as earth science/geology, crop science, agronomy, environmental science, or plant physiology. Doctoral and masters institutions were more likely to have ISSe instructors with a primary soil science background (85 and 89%, respectively) than baccalaureate or associate institutions (45%). Land-grant institutions were more likely to have ISSe instructors with primary soil science backgrounds (88%) than non-land-grant institutions (69%), which were more likely to have ISSe instructors whose primary academic background was a closely related field.

Student Populations

Self-reported class size for each offering of the ISSe course averaged 66 ± 30 students among all respondent institutions (Fig. 1, Supplemental Table S1), with significant ranges in class size (from less than 20 students to more than...
Fig. 1. Self-reported average introductory soil science or equivalent course size among (A) Carnegie classification, (B) land-grant status, and (C) all respondents; proportion of students by year in school among (D) Carnegie categories, (E) land-grant status, and (F) all respondents; and proportion of students taking the course to satisfy various requirements among (G) Carnegie categories, (H) land-grant status, and (I) all respondents student populations. Detailed numbers and statistics for this same data are provided in Supplemental Table S1.
100 students) across all respondent institutions. Doctoral institutions had significantly larger class sizes per course offering (78 ± 25 students) than masters, baccalaureate, and associate institutions (30 ± 14), and land-grant institutions had significantly larger class sizes (85 ± 23) than non-land-grant institutions (39 ± 23) (Fig. 1, Supplemental Table S1). Although a numerically decreasing trend in ISSe enrollment exists between masters, baccalaureate, and associate institutions (Table 1), given the much smaller samples size of some of these groups the differences were not statistically significant (Supplemental Table S1, Tukey’s HSD, p > 0.1 in all cases).

Among all respondent institutions, juniors (29% ± 12%) were the largest represented class group, followed by sophomores (24% ± 12%) and seniors (21% ± 12%) (Fig. 1, Supplemental Table S1). Freshmen (14% ± 16%), graduate, and non-degree students (6% each) were the smallest groups, on average. There were no significant differences between Carnegie or land-grant categories for proportions of students of different class categories (freshman, sophomores, juniors, and seniors). However, doctoral and masters institutions had fewer non-degree students (3% vs. 16–26%, respectively) than baccalaureate and associate institutions. Additionally, land-grants appeared to have a lower proportion of graduate (4% vs. 12%) and non-degree (4% vs. 16%) students than non-land-grant institutions (Fig. 1, Supplemental Table S1).

Across all institutions, ISSe instructors self-reported that 66% of their students enrolled in the course to satisfy a major or minor requirement, 20% of students were enrolled to satisfy a general education requirement, and 14% of students were enrolled in the course as an elective. There were no significant differences in these numbers between Carnegie categories. However, land-grant institutions had a significantly lower proportion of students taking the course as an elective (9%) than non-land-grant institutions (19%) (Fig. 1, Supplemental Table S1).

**Student Certifications**

With the exception of associate institutions, all respondents self-reported estimates of at least a portion of ISSe students eventually going on to achieve certification as Certified or Licensed Professional Soil Scientist (8%), Certified Wetland Delineators (or equivalent) (6%), or Certified Professional Agronomist/Certified Crop Advisor (15%). No significant differences were detected between Carnegie or land-grant categories for this metric.

Exam fees for the FSS exam were subsidized for students by 7% of respondent institutions. The institutions that subsidized these fees were all doctoral institutions, six of which were land-grant institutions, and one of which was a non-land-grant institution. Fifty percent of responding institutions reported incorporating the FSS examination performance objectives (SSSA, 2012) into their ISSe course structure or curricula. Forty-seven percent of doctoral institutions reported incorporating FSS performance objectives into the course, and 58% of masters and baccalaureate institutions reported incorporating FSS objectives. Neither of the two responding associate institutions reported incorporating FSS performance objectives into the course. These percentages did not vary significantly by land-grant category.

**Prerequisites and Course Requirement Fulfillment**

Chemistry was the most common prerequisite for ISSe courses, with 54% of respondents requiring chemistry, followed by college-level algebra (20%) (Table 1). Physics,
biology/plant science/crop science, and geology/earth science were the least commonly required prerequisites (Table 1). No respondent doctoral or land-grant institutions required geology/earth science. However, three masters and baccalaureate institutions reported a geology/earth-science course as a prerequisite to the ISSe course. Prerequisites were not required by 13% of respondent institutions (Table 1). More doctoral institutions did not have college-level prerequisite courses (15%) relative to masters, baccalaureate, and associate institutions (7%, classes combined) (Table 1). The ISSe course is also more likely to be taught in a department that offers a soil science major or minor at doctoral (78%) and land-grant institutions (39%). However, departments offering a soil science “option” or “track” were much more evenly spread among Carnegie categories (Table 1). Among all respondents, ISSe courses predominantly satisfied major or minor requirements (91% of respondents), with approximately half of courses (53%) satisfying a general science or laboratory requirement (Table 1). The ISSe course is more likely to satisfy a major or minor requirement and general science or lab requirement at land-grant institutions (97 and 66%, respectively) than non-land-grant institutions (83 and 41%, respectively).

**Textbooks**

Among all respondents, 81% required a textbook, 39% recommended a textbook, and 23% both required and recommended a textbook (Table 1). Non-land-grant institutions (85%) and non-doctoral institutions (93%) were more likely to require a textbook for the ISSe course than were land-grant institutions (79%) and doctoral institutions (73%) (Table 1). Instructors who required textbooks predominantly favored the unabridged *The Nature and Properties of Soils* (Weil and Brady, 2017, 34%), or abridged *Elements of the Nature and Properties of Soils* (Brady and Weil, 2010, 25%). However, significant diversity in required textbook choice existed, with 18% of respondents requiring other texts, including: *Know Soil, Know Life* (Lindbo et al., 2012, 5%), *Soil Science Simplified* (Franzmeier et al., 2016, 5%) (Table 2), and other texts (Supplemental Table S2). Five of the six textbooks that were reported as required by more than one respondent (Table 2) were utilized at doctoral and masters institutions (with the exception of *Soil Science and Management* [Plaster, 2013], which was required only at baccalaureate institutions). Although responses were limited, associate respondents reported using only the Brady and Weil (2010) and Weil and Brady (2017) texts. Instructor-specific course notes or text were reported as required by 3% of respondents. However, given that 19% of respondents did not require a textbook, it is likely that a higher proportion of ISSe courses use instructor-specific course or lecture notes, but simply did not indicate that these were required materials. No open textbooks were listed by any respondents for primary texts, indicating a potential need for open or alternative textbook options in ISSe courses.

Land-grant institutions (42%) and doctoral institutions (44%) were more likely to have recommended textbooks than non-land-grant institutions (37%) and masters, baccalaureate, and associate institutions (32%). Among all respondents, approximately 23% both required and recommended a textbook, which did not vary between Carnegie or land-grant categories. Fewer respondents used recommended texts, but in these recommended texts, a large diversity in topical content was revealed. In common pattern to required texts, *The Nature and Properties of Soils* (Weil and Brady, 2017, 10%) and *Elements of the Nature and Properties of Soils* (Brady and Weil, 2010, 8%) were the most predominant choices of recommended text; however, nine other textbooks were reported as recommended textbooks among all respondents (Table 2, Supplemental Table S2). As a whole, non-land-grant institutions utilized seven of the eight potential required texts and 7 of the 11 potential recommended textbooks, whereas land-grant institutions utilized six of the eight potential required texts and 10 of the 11 potential recommended textbooks (Table 2, Supplemental Table S2).

**Topical Content**

Among the 36 generalized topical areas (see the “Methods” section), the most deeply taught topics among all respondents were soil water concepts (5.43), soil classification and taxonomy (5.17), horizon forming processes and horizon nomenclature (5.04), pH and its effects on other soil properties (5.03), and soil forming factors and soil development (5.01). Based on our rating scale, these five topics were the only of the 36 topical categories that had, on average (among all respondents), at least one complete lecture, laboratory, or discussion section devoted solely to them, with two (soil water concepts, and soil classification and taxonomy) averaging multiple integrated lecture, laboratory, or discussion sections (Table 3).

**Table 2. Prevalence of required and recommended textbooks used by more than one respondent in introductory soil science or equivalent (ISSe) courses among all respondents (not just those that require or recommend). A complete list of textbooks used by all respondents can be found in Supplemental Table S2. Names of textbooks listed do not constitute endorsement by the authors of this article.**

<table>
<thead>
<tr>
<th>Textbook title</th>
<th>Authors</th>
<th>Publisher</th>
<th>Required</th>
<th>Recommended</th>
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<tbody>
<tr>
<td><em>Elements of the Nature and Properties of Soils</em></td>
<td>N.C. Brady and R.R. Weil</td>
<td>Pearson</td>
<td>25</td>
<td>8</td>
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<tr>
<td><em>Know Soil, Know Life</em></td>
<td>D.M. Lindbo, D.A. Kozlowski,</td>
<td>Soil Science Society of</td>
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<td></td>
<td>C. Robinson</td>
<td>America</td>
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<tr>
<td><em>Soil Science Simplified</em></td>
<td>D.P. Franzmeier, W.W. McFee,</td>
<td>Waveland Press</td>
<td>5</td>
<td>3</td>
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<td></td>
<td>J.G. Gravel, and H. Kohnke,</td>
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<tr>
<td><em>Soils: An Introduction</em></td>
<td>M.J. Singer and D.N. Munns,</td>
<td>Pearson</td>
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<td>2005</td>
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<tr>
<td><em>Soil Science and Management</em></td>
<td>E.J. Plaster, 2013</td>
<td>Cengage Learning</td>
<td>3</td>
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<tr>
<td><em>Soils: Genesis and Geomorphology</em></td>
<td>R.J. Schaetzl and M.L. Thompson,</td>
<td>Cambridge University Press</td>
<td>&lt;1</td>
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<td></td>
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<td>Instructor- or institution-specific course or lecture notes</td>
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Of these five critical topical categories, "soil forming factors and soil development" was taught most heavily in lecture (86%), whereas "pH and its effects on other soil properties" was taught least heavily in lecture (58%) and most heavily in laboratory (40%) than the other categories (Table 3). Soil horizon formation and horizon nomenclature was taught most heavily in the field (12%). Soil water concepts, the most deeply taught topical category, was taught the majority of the time in lecture settings (72%), followed by laboratory settings (26%) (Table 3).

For topical categories ranked lower than the five most deeply explored topics, the topics taught most heavily in lecture settings among all respondents were the hydrologic cycle (89%), N cycle (80%), and C cycle (79%) (Table 3). Topics taught most heavily in laboratory settings among all respondents were mapping and map unit interpretations (55%), particle size and texture (54%), and soil testing and analysis (49%) (Table 3). Finally, topics taught most heavily in field environments were soil geomorphology (19%), soil color (15%), and soil structure (14%).

The most shallowly taught topics among all respondents were precision agriculture (2.22), urban soils (2.36), engineering properties (2.37), geographic information system (GIS) and soils information integration (2.97), and phyto- or bioremediation and waste management (2.98). These topics were, on average, mentioned at least briefly and not explored, or had less than half of a lecture laboratory or discussion section devoted to them.

When the 36 topical categories were each placed into one of four broad sub-discipline foci (physical properties, biological properties, chemical properties, or classification/genesis), the median ranking (from 1 to 36) of topical foci in chemical properties and classification/genesis was 18, whereas the median rankings of topics in physical and...
biological properties was 21.5 and 25, respectively. The number of topics that placed in the top 10 most deeply taught among these four broad foci was chemical properties and classification/genesis (4), physical properties (2), and biological properties (0).

Course Delivery

Eighty-seven percent of responding institutions reported predominantly classroom delivery for their ISSe courses, but 16% reported hybrid (classroom and online) delivery, and only 8% reported online-only delivery. These proportions differed significantly between Carnegie and land-grant categories. Hybrid approaches to delivery were most common among doctoral and masters institutions (19 and 17%, respectively), and least prevalent among baccalaureate and associate institutions (9 and 0%, respectively) (Fig. 2, Supplemental Table S3). Hybrid approaches were more prevalent among land-grant (23%) than non-land-grant institutions (10%) (Fig. 2, Supplemental Table S3). Note that among categories, these statistics do not add up to 100%, because some institutions reported offering concurrent sections of the ISSe course that differed significantly in their delivery methods.

Online-Only Course Delivery

Online-only course delivery was reported by 11 institutions (nine land-grants and two non-land-grants or nine doctoral, one masters, and one associate institution). Of the 11 institutions offering a completely online or distance learning format, the self-reported average class size was 39.5 students. Significant variation was reported, however, ranging from less than 10 students to more than 100 students per course offering. Among all institutions offering an online-only section, the average audience is predominantly undergraduates (79%), followed by graduate students (22%), continuing education (14%), and non-degree students (15%). Two respondent institutions reported having online or distance-only programs that are specifically tailored to graduate students, professionals, and continuing education students instead of undergraduates. A total of 54% of these institutions (six institutions) offer the online-only section for graduate credit, and 45% of those offering an online section (five institutions) have a laboratory section in conjunction with the distance learning format. Fifty-five percent of institutions offering online course delivery use recordings of live lectures (presumably from the classroom delivery version of the ISSe course) in the online version.

Non-Laboratory Pedagogical Approaches

Normalization of self-reported non-lab pedagogies in the ISSe course for each institution resulted in an estimate of the prevalence of various pedagogies across the entire non-laboratory curriculum. Among all respondents, an estimated 56% of ISSe course hours were taught using a standard lecture format, whereas 22% of course hours were taught using an active learning environment (Fig. 2, Supplemental Table S3). Approximately 9% of course hours were taught using an online learning management system, whereas 7, 4, and 3% of course hours were taught using peer-learning, flipped classroom, and studio-style pedagogies (Fig. 2, Supplemental Table S3). No significant relationship between class size and proportion of the course taught as traditional lecture was detected, and there were no significant differences between Carnegie or land-grant categories.

Among all respondent institutions, 28% reported having a discussion section as a part of their ISSe course. These did not vary by Carnegie classification, but land-grant institutions were much more likely to have discussion components (43%) compared with non-land-grant institutions (13%).

Laboratory Approaches and Pedagogies

Ninety-two percent of respondent institutions reported offering a laboratory component, of which 27% offer the laboratory component as a separate course. The average class size for each laboratory section was approximately 19 students and did not vary significantly between Carnegie or land-grant categories. Of these respondent institutions, 97% reported having defined laboratory periods, with only 3% (two respondent institutions) offering self-paced laboratories (the University of Minnesota and Purdue University). Among institutions offering a laboratory component, an average of 50% of laboratory time was taught using wet laboratory activities (with students doing benchtop activities), whereas 20% of laboratory time was conducted in the field, 17% conducted through exhibits that students observe and interpret, and 9% of laboratory activities were conducted completely digitally or through the use of an online learning management system (OLMS) (Fig. 2, Supplemental Table S3).

Seventy-six percent of respondent institutions had field trips integrated into the laboratory component of the course. Among all respondent institutions, an average of 2.2 ± 1.3 field trips were conducted per course offering. These field trip numbers were not significantly different between Carnegie and land-grant categories, and at least among respondents who provided an email address for institutional identification, did not vary by latitude.

Across all respondent institutions, 71% of primary instructors were involved in leading laboratory sections. However, doctoral (63%) and land-grant (66%) institutions had lower levels of primary instructor involvement than masters, baccalaureate, and associates institutions (96%) and non-land-grant (84%) institutions. Graduate teaching assistants (TAs) were involved in leading the laboratory component at doctoral and masters institutions (67 and 35%, respectively). Graduate TAs were involved in leading laboratory sections at 71% of land-grant institutions, but they were involved in the laboratory component of only 24% of non-land-grant institutions. Undergraduate TAs were reported as leading the laboratory component for 12% of doctoral institutions and 10% of baccalaureate institutions. No undergraduate TAs were reported as leading the laboratory sections for masters or associate institutions. Staff or other instructors lead the laboratory component at 7% of doctoral and 6% masters institutions, with no significant differences between land-grant and non-land-grant categories.

Among institutions that have a laboratory component, 73% of respondents reported using a custom laboratory manual, 8% reported using a commercially published manual, and 19% reported using no laboratory manual or course-specific notes. These laboratory materials are provided at no cost to the student at 51% of institutions, with 49% of institutions with laboratory components report student costs associated with accessing or purchase of laboratory materials.
Fig. 2. Self-reported proportion of total introductory soil science or equivalent course time spent using various learning strategies (A) in non-laboratory components of the course among all respondents; in laboratory settings among (B) Carnegie categories, (C) land-grant status, and (D) all respondents; and primary method of course delivery among (E) Carnegie categories, (F) land-grant status, and (G) all respondents.
A number of publications approximately a decade ago focused on a decline in the number of soil science majors and departments in the United States and across the world (Baveye et al., 2006; Hansen et al., 2007; Hartemink et al., 2008; Hartemink and McBratney, 2008). However, a subsequent survey of soil science departments in the United States by SSSA did not identify such a trend (Havlin et al., 2010), and recent studies have shown an increasing trend in undergraduate programs and ISS$_S$ enrollment in the United States (Brevik et al., 2014, 2018) and steady to projected ISS$_S$ enrollment at Canadian institutions (Diochon et al., 2017). From the perspective of ISS$_S$ courses, declining trends in majors and departments may have had limited impact on ISS$_S$ student populations (Collins, 2008), because of a strong demand for teaching soil science from many different fields (Hansen et al., 2007).

The self-reported class sizes among all survey respondents for individual ISS$_S$ course offerings here are broadly consistent with those from another recent study in the United States (Brevik et al., 2018), which reported annual student numbers for 10 institutions on semester schedules, with two course offerings per year. Brevik et al. (2018) reported annual median class sizes between 160 and 175 (an approximate average of 80–87 students per offering) in ISS$_S$ courses among 10 institutions (five land-grant, five non land-grant; five doctoral, four masters, one baccalaureate) between 2009 and 2013. Our mean self-reported course size for individual offerings of ISS$_S$ was 66 students among all institutions, 78 students for doctoral institutions, and 85 students for land-grant institutions.

Consistent with previous studies that have considered the discovery nature of soil science as a discipline and the effects of that discovery process on student recruitment and program size (Collins, 2008), the self-reported class demographics from respondent institutions reflect a preponderance of students in late undergraduate (junior or senior status), graduate, or non-degree status (62% combined among all respondents). Survey responses revealed that doctoral and masters institutions had lower numbers of non-degree students taking ISS$_S$ courses compared with baccalaureate and associate institutions. Additionally, non-land-grant institutions had a higher number of graduate and non-degree students taking introductory soils.

Despite a seemingly late entry into ISS$_S$ and declining prevalence of soil science majors and minors (i.e., Baveye et al., 2006; Hartemink et al., 2008; Hartemink and McBratney, 2008; Hansen et al., 2007), two-thirds of students (66%) in ISS$_S$ courses were taking the course to satisfy a major or minor requirement. This result likely means that many students may be taking ISS$_S$ as a requirement for a closely related major, which supports the idea that ISS$_S$ education is in high demand by many fields (Hansen et al., 2007). This is congruent with the results of Brevik et al. (2018), who showed that increased enrollment in U.S. soil science classes in general and in ISS$_S$ specifically has been driven by students from fields such as environmental science or engineering.

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The prevalence of ISS$_S$ instructors holding a Ph.D. in our survey (92%) appears to be higher than that reported in a survey of Canadian institutions (86%) (Krzic et al., 2018), perhaps in part because the Canadian survey included a higher proportion of baccalaureate and associate institutions. The proportion of ISS$_S$ primary instructors at the full professor and associate professor ranks in our survey (38 and 27%, respectively), were broadly comparable to the proportion of the same ranks in the Canadian survey (33 and 26%, respectively; Krzic et al., 2018). However the proportion of ISS$_S$ primary instructors at the rank of assistant professor in our survey (21%) was double that reported in the Canadian survey (10%). This may mean that institutions in the United States, regardless of land-grant status or Carnegie classification tend to be more permissive in allowing younger, tenure-track faculty to teach ISS$_S$ courses. It is likely that this primary instructor demographic may also be infusing a range of new ideas into ISS$_S$ courses that could influence teaching approaches. Finally, it appears that the ISS$_S$ instructor respondents in our survey were much more likely to have a disciplinary background in soil science (78%) than in the Canadian survey (41%). This finding may be a reflection of either additional loss of soil science faculty and departments in Canada relative to the U.S. (Baveye et al., 2006), or a result of the larger proportion of baccalaureate and associate institutions in the Canadian survey. In the latter case, this would be consistent with our survey results of decreasing proportions of soil science backgrounds for ISS$_S$ primary instructors among baccalaureate and associate institutions, which must attract faculty that can serve as generalists and often teach courses in multiple disciplines.

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that approximately 20% of students were enrolled to satisfy a general education requirement. Therefore, it seems that opportunity remains to increase the percentage of students taking ISSe courses for general education and elective credits. With regard to recruiting non-degree or undeclared students (Collins, 2008), our data suggests that non-land-grant institutions have more experience and success in this regard.

A further recommendation that emerged from Havlin et al. (2010) included “enhancing the soil science curriculum to ensure that students graduate with appropriate and functional field skills” and that SSSA should provide relevant departments with specific learning goals and objectives. Our survey results show that approximately half of respondent institutions incorporated specific learning objectives into their ISSe course. Finally, Havlin et al. (2010) recommended encouraging “certification and state licensing as a natural step in the career process, and that SSSA should help facilitate certification programs and state licensing by integrating the fundamentals exam into soil science curricula.” Although instructors estimated that approximately 8% of the students in their ISSe course might go on to take the FSS exam, less than 10% of departments offered some kind of subsidy or incentive for students to take the exam. Therefore, it seems that there is significant room for integration of FSS exam objectives across the ISSe curriculum, as well as increased support for students who choose to take higher-level courses in soil science to sit for the FSS exam.

With regard to the development of functional field skills as recommended by Havlin et al. (2010), ISSe courses (due to their broad content) cannot be the sole provider of these skills, which are more appropriately solidified by specialized advanced courses. However, ISSe courses do provide important introductory field experiences and skill development for many students. With an average of more than two field trips per ISSe course offering among all respondents, it appears that given the significant constraints on time and resources for ISSe courses, incorporation of field experiences is robust.

**Prerequisites, Course Materials, and Topical Foci in Introductory Soil Science or Equivalent Courses**

Chemistry and college-level algebra were by far the most common prerequisites reported for ISSe courses in our survey. However, earth science/geology, and plant science/biology/crop science were also categories of prerequisites that were shared by more than one institution. Interestingly, doctoral institutions appeared to be less likely than non-doctoral institutions to require prerequisites. The results of our topical analysis indicate that in ISSe courses, chemical properties, and soil classification/development are emphasized over physical and biological properties, which may be the result of either instructor background or a long-standing connection of ISSe content to production agriculture (Collins, 2008; Brevik et al., 2014).

In a recent Canadian survey of ISSe courses (Krzic et al., 2018), only 52% of surveyed ISSe courses required a textbook and 18% recommended a text. In our survey, 81% of institutions required a textbook, 39% recommended a textbook, and 23% both required and recommended a text. Therefore, it appears that U.S. institutions are more likely than Canadian institutions to both require and recommend a textbook. Of the textbooks listed in the Canadian survey, all appear on the list for our survey except one general text and three Canada specific texts.

A total of eight unique texts were listed as required, whereas a total of 13 unique texts were listed as recommended, with a final total of 16 unique texts utilized as a whole (this does not include instructor or custom notes as a “text” material). Most of the titles of the required texts are general textbooks, but one is an upper-level choice (Schaeztl and Thompson, 2015; Soils: Genesis and Geomorphology). Recommended texts, although used by less than 40% of instructors, reveal a large diversity in instructor perspectives and ISSe learning objectives.

Jarvis et al. (2012) reported several categories of soil science knowledge, skills, and abilities rated as important by a survey of 26 academics, six government employees, and seven industry professionals. Among their six broad categories, the highest rated topical categories included physical, chemical, and biological processes of soil, nutrient cycling, water movement, and water quality. The results of our topical survey of ISSe courses show broad alignment with these topics, with the caveat that ISSe courses tend to be more heavily weighted toward chemical processes (both in content and prerequisites) than physical or biological processes. It is encouraging then, that in light of the Jarvis et al. (2012) survey, soil water concepts emerged as the most deeply taught topical category among all respondents of our survey, with multiple integrated lecture, laboratory, or discussion sessions typically spent on the material.

Havlin et al. (2010), in a large survey of potential employers, identified the following topics or skill sets as the three most important for graduates: soil classification or survey, soil physical property or engineering assessment, and wetland soils. It appears that ISSe courses are not well equipped to address two of these topical areas or skill sets (soil physical properties or engineering assessment and wetland soils). In our topical survey, engineering properties and redox processes/hydric soils were among the most shallowly taught topics in ISSe courses. However, soil classification and taxonomy was the second most deeply taught topical area in ISSe courses. Although there appears to be a mismatch in topical area focus of ISSe courses with the Havlin et al. (2010) employer survey, this may not be a major concern. First, ISSe courses typically contain broad surveys of chemical, physical, and biological properties, which serve as a foundation for students who go on to take upper level soil science courses, and second, one of the three major skill sets identified in Havlin et al. (2010) is indeed a deep focus of most ISSe courses (soil classification and taxonomy).

**Pedagogies and Teaching Methods Utilized in Introductory Soil Science or Equivalent Courses**

Our survey results show that pedagogies in non-laboratory settings in ISSe courses are diverse. Among all non-laboratory ISSe course hours, instructors estimated that only slightly more than half (56%) were taught using a traditional lecture format, whereas active learning environments, online management systems, peer-learning, flipped classroom, and studio-style approaches were used for approximately 44% of ISSe course hours. There was no consistent, significant relationship detected between class size, land-grant status, or Carnegie classification and the percentages of these teaching styles. This appears to indicate a higher percentage of diverse teaching approaches employed in the respondents
of our survey than those reported in a survey of Canadian institutions, which indicated that lectures were a much more predominant form of teaching style (Krizc et al., 2018). These results appear to show that the ISSe instructors surveyed in our study tend to be highly innovative, regardless of their professional background or academic position. This is congruent with previous qualitative studies that focused on a strong passion for teaching soil science among instructors (Hartemink et al., 2014). Field et al. (2011) conducted an assessment of teaching principles in soil science and emphasized the need for increased focus on fieldwork, active learning, topical connections, and systems approaches. Our survey suggests that ISSe instructors from all backgrounds and institutions are implementing a number of these principles.

These results suggest that there is a market and strong demand among ISSe instructors for alternative teaching strategies and approaches in the classroom. The interdisciplinary and tangible nature of ISSe courses make the content prime for the implementation of alternative learning styles and discipline-specific approaches such as problem or case-based learning (Amador and Gorres, 2004; Strivelli et al., 2011; Goldsmith, 2011), or active learning activities from closely related fields (McConnell et al., 2003). The assessment and publication of ISSe course activities, even in lecture settings (e.g., Turk, 2016) should therefore be strongly encouraged.

**Opportunities for Cross-Institutional Cooperation or the Development of Multi-User Course Materials and Resources**

Forty-two percent of survey respondents indicated strong interest in connecting with other instructors to explore new approaches and materials. Therefore, there is community momentum for the continued development of shared experiences and open-source materials. We suggest several recommendations that may assist with this:

1. Given the pedagogical diversity revealed in this survey, it is clear that ISSe instructors should continue to publish and present unique and innovative approaches to teaching in all settings.

2. Emphasis on the development of open educational resources should be encouraged (Moorberg and Crouse, 2017). The results of our ISSe topical survey suggest two potentially fruitful paths for prioritizing topical areas for development: emphasis on high-impact materials for deeply taught topics, or emphasis on the development of ISSe-appropriate materials for shallowly taught topics. In the case of the former, emphasis could be placed on the update and modernization of intensively utilized material in deeply taught topics, such as an update of the classical *Water Movement in Soils* film (Gardner and Hseih, 1959), which was last updated by the University of Arizona and USDA-SCS in 1994 as “How Water Moves through Soils” (Watson et al., 1995) and is in strong need of modernization for today's ISSe students. Conversely, shallowly taught ISSe topics may be an opportunity for experts in those fields to produce material that is relevant to an ISSe audience. Topics such as precision agriculture, soils and GIS integration, and remediation or waste management, due to their applied nature, could be extremely interesting to ISSe audiences if materials could be integrated into ISSe curricula as applications of basic principles.

**CONCLUSIONS**

The results of our survey indicate a robust and innovative set of ISSe courses in the United States across land-grant and Carnegie classification categories. It appears that student numbers are stable or increasing, and that courses are generally supported by highly engaged, well-trained instructors. Nevertheless, significant opportunities remain for recruiting students from non-majors and expanding the student base in ISSe courses. Most importantly, a majority of ISSe instructors are strongly interested in developing a community of engagement with other instructors. New efforts centered on the development of open-source materials and technologies may yield dividends in improving ISSe courses nationally and expanding the reach and scope of these courses to train a new generation of students in soil science.

**SUPPLEMENTAL MATERIAL**

Table S1. Self-reported average introductory soil science or equivalent course size and student population.

Table S2. Complete list of textbooks used by all respondents in introductory soil science (or equivalent) courses among all respondents. Names of textbooks listed do not constitute endorsement by the authors of this article.

Table S3. Self-reported introductory soil science (or equivalent) course percentage of total course time spent utilizing various learning strategies.

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**REFERENCES**


