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Field science in the age of online learning: Dynamic instruction of techniques to assess soil physical properties

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Soil physical properties, such as soil texture, color, bulk density, and porosity are important determinants of water flow (e.g., infiltration and drainage), biogeochemical cycling, and plant community composition. In addition, they reflect the environment in which the soil developed, giving insight into climate, mineralogy, and land cover. While many soil assessments require sophisticated laboratory equipment, some can be made simply by a trained individual, requiring only practice and reference materials. For students in environmental fields, it is particularly important and empowering to learn how to make informed soil observations that provide insights from the soil pedon to the landscape and that can be done within the field setting. Drawing on updated pedagogical approaches, including active learning, small group collaboration, and metacognitive exercises, this paper presents a course module for teaching soil texture and color analysis in the field that can be modified for students from secondary through graduate school. The combination of asynchronous, pre-course readings and assessment; synchronous, in-class instruction, hands-on practice, and application activities; and post-class reflection give students the opportunity to build a strong foundation for making soil observations. This course module is suitable for both in-person and remote learning modalities and can be adapted to a number of course topics across environmental disciplines. Ultimately, the goal is to provide students with exciting, hands-on training that inspires them to learn more about soils regardless of the learning platform.

KEYWORDS
soil texture, soil color, remote online learning, active learning, environmental science, STEM education

Introduction

Accurately determining the biological, chemical, and physical properties of soils is critical to address questions across many environmental fields, including agronomy, soil science, watershed hydrology, biogeochemistry, critical zone science, and ecosystem science (see Rasmussen et al., 2018; Hammond et al., 2019; Soong et al., 2020). Often, assessing soil properties requires that samples be transported from the field to the laboratory for analysis (Gee and Or, 2002). However, observations of soil texture—the proportions of sand, silt, and clay—and soil color—an indicator of mineralogy and environmental conditions—can be made relatively easily and accurately in the field. While new Smartphone applications exist to diagnose some soil properties (e.g., LandPKS), developing one's own ability to infer information from soils based on training and expertise is valuable. It is helpful and empowering, particularly for students in environmental disciplines, to learn the simple, hands-on techniques that build confidence, capacity, and intuition in the field.

We developed the following course module to teach students interpretation of the soil texture triangle, the "texture-by-feel" method, and assessment of soil color. They combine their observations with concepts gained from asynchronous, pre-class readings to make informed guesses about the origins of soils that are previously unknown to them. We have taught this course module for many years and primarily in person (**Figure 1**), providing an engaging, tactile experience for students to learn about the world beneath their feet. However, when the COVID-19 pandemic began, we adapted it to the online (e.g., Zoom) learning environment. Even remotely, we discovered ways to make the exercise engaging, fun, and effective for achieving the desired learning objectives. We believe that it is applicable to a number of courses across environmental fields. The module can be adjusted to the focus of the course content, student level (middle school through graduate school and continuing education programs), as well as the nature of the program—from general science to research to professional programs.

Here we describe the complete course module and provide all supporting materials to teach it in person or using an online learning environment (see **Supplementary Materials**); both modalities provide multiple approaches to foster enthusiasm and curiosity about soils regardless of students' abilities or previous interest (Riener and Willingham, 2010). This approach to instruction is aligned with current best practices for increasing student learning outcomes, including: (1) flipped classroom, or assigning asynchronous pre-class content learning and assessment (Bishop and Verleger, 2013); (2) active learning or focusing on students tackling challenging activities during class, rather than listening to an instructor lecture (Bonwell and Eison, 1991; Johnson and Johnson, 2008); (3) small group work to build confidence, collaboration, and community (Towns et al., 2000); and (4) metacognitive exercises, or providing post-class opportunities for students to write and reflect on their learning (Dunlap, 2006; Zarestky et al., 2022).

Pedagogical framework

Overview

There are three main components of this in-class exercise: (1) *conceptual learning*—reinforcing the information that texture and color reflect about soils; (2) *skills building*—introducing hands-on techniques to assess soil texture and color; and (3) *synthesis/interpretation*—integrating background knowledge and evidence to determine the origin of unknown soils and the characteristics of the environment from which they came. Outside of class, students will complete pre-class readings and assessments, and post-class challenge questions and journaling to reflect on their experience and knowledge gains. This structure is consistent with flipped classroom learning, in which students come to class prepared with conceptual knowledge and can work on problems/skill-building more collaboratively (Love et al., 2015; Koh, 2019). Here, we describe the flow of the class. Depending on the length of the class period, instructors could complete this activity in one session (e.g., one 75-min to 2 h plus period), or divide it into two (e.g., two 1 h periods). It is possible to expand on one or more topics if the class time permits.

Students will come to class having read background materials on soil physical properties, as well as any topically relevant materials chosen by the instructor that link soil physical properties to broader concepts taught in the class (e.g., watershed hydrology, soil science, critical zone science, ecosystem science). This course module can be completed before or after a lecture or discussion about soil physical properties. Following the module, the instructor may choose to take the material in a number of different directions, depending on the focus of the course (as described later). However, we strongly recommend including the post-class metacognition activities (examples included in the **Supplementary Material**). We have found that having students examine their learning gains and skills acquisition not only helps to build their confidence and motivation, but also allows the instructor to adapt the following class periods to support student needs. These observations are consistent with multiple studies evaluating the use of metacognitive exercises throughout a course (e.g., weekly journaling), including Karaali (2015), Dang et al. (2018), McCabe and Olimpo (2020), among others.

Materials

Typically, we provide 3-5 unknown soils for students to use in this exercise. We have requested standard soils from

FIGURE 1
Undergraduate students **(A)** work collaboratively to describe several soil unknowns, **(B)** practice the "texture by feel" method, and **(C)** determine color analysis of soil unknowns. While these pictures show students learning the techniques in person, they can also be taught effectively using online learning platforms (Photos by E.S. Hinckley).

the Utah State University[1], or prepared soils local to our universities for analysis. Either source is useful: standard soils come with metadata and are already prepared for soil texturing, while local soils provide students with an opportunity to think about the soils' origin in a place with which they are familiar. When using local soils, we have often included 100% sand purchased from a local hardware store. Students might guess that this unknown comes from a beach or riverbank; the "trick" provides opportunities both to discuss the difference between intact, upland soil environments and others—a common misconception that upland soils are everywhere—and to handle an end member. When choosing unknowns, the key is to provide students with a range of soil texture classes to experience and practice their technique.

In addition to soils, students need a bottle filled with tap water (a sports-style squeeze bottle with straw works well), handouts explaining the techniques (see **Supplementary Material**), data table, and a copy of the Munsell color chart as a hardcopy book or via free application for Smartphones, of which there are several options available (e.g., Color Meter or Color Analyzer for iPhone).

1 https://agclassroomstore.com/soil-samples-soil-texture/

Preparation of soil unknowns

If the instructor is going to collect soils locally for this exercise, then they must be sieved through 2-mm mesh (rocks and organic matter removed), spread on pans and oven-dried at 105°C for 48-h. This procedure isolates the fraction that meets the standard definition of soil for texturing—the fine earth fraction that is $\leq$ 2 mm (Weil and Brady, 2016). If teaching this exercise using an online platform, it is necessary to divide each unknown soil into individual plastic bags (~200 g per bag) labeled with a code (e.g., number or letter) – and prepare one for each student. Each student will get 3-5 bags of (unique, unknown) prepared soil. If using soils obtained locally (not from a laboratory providing standards), then instructors will need to determine soil texture and color prior to teaching the activity.

The preparation and distribution of soils for this activity assumes that students will be able to pick up activity kits containing all needed materials from a central location (e.g., the university/college). If students are not able to pick up kits—for example, if they are not living near their school or university—it is possible to mail kits to them or have them collect bags of soil from their local area. Likely, they will not have access to soil processing equipment but could break up soils and remove coarse organic matter and rocks by hand, then air-dry the soils in an open bag until the class period. The instructor can discuss in class that this approximates properly prepared soils; the ability to practice and grow comfortable with determining soil texture and color will not be compromised, and it is possible to do the techniques properly and immediately with soil collected in the field.

Preparatory materials

Prior to conducting this exercise, students should complete background reading related to soil physical properties and their relationship to water flow, plant growth, and/or biogeochemical cycling. We recommend *The Nature and Properties of Soils* (Weil and Brady, 2016), Chapter 4: Soil Architecture and Physical Properties to cover the basics of soil texture and color (or equivalent). Additional texts could come from other topical areas, dependent on the focus of the course (e.g., watershed hydrology, ecosystem science, soil chemistry). The instructor may consider giving a post-reading quiz to assess students' assimilation of key concepts.

Learning environment

Learning objectives

This activity has four primary learning objectives:

1. Demonstrate ability to interpret the soil texture triangle.
2. Demonstrate ability to use the "texture by feel" method to determine different soil textural classes.
3. Demonstrate ability to determine soil color using the Munsell color chart (or Smartphone application).
4. Synthesize observations to make an informed guess about unknown soils' likely origin.

In-class exercise kits

Students will need:

- 3-5 prepared soil unknowns in plastic bags, labeled with a code (e.g., A-E or 1-5).
- Squirt bottle filled with water.
- Munsell color chart (hardcopy book or downloaded application for Smartphone, such as Color Meter or Color Analyzer for iPhone).
- Handouts with texture triangle, method for texturing by hand (as a visual flow chart).
- Assignment with instructions, question prompts, and data table.

Class plan

Students enter the main room of the online learning platform prepared with their activity kits. Worksheets that provide the instructions and data table for students' answers and interpretations may be completed online via a learning management system (e.g., Canvas or Desire2Learn) or hardcopy during the exercise, depending on the desire of the instructor. We suggest opening class by establishing small groups of three students who will work together during the breakout sessions. Students will be sent periodically into virtual breakout rooms to collaborate; the instructor, and, if present, teaching assistants, can visit these breakout rooms to check on students' progress and observe the quality of their technique.

After welcoming students, send them into breakout rooms to discuss their responses to the following prompts:

1. Why do we assess soil texture and color?
2. What can these measurements tell us about overall soil, ecosystem, or watershed function?

In ~10 min, return students to the main room and do a whole class report-out of their group's responses. Instructor and/or teaching assistants can fill in any additional gaps. This initial discussion establishes the foundation for the exercise and reinforces concepts introduced in the pre-class readings. Next, introduce the supporting materials for the in-class exercise, including how to use the soil texture triangle, read the flow chart to conduct the texture by feel method, and use Munsell color charts (see **Supplementary Materials**). At this stage, instructors may choose to give a couple of different combinations of percent sand, silt, and clay (summing to 100), so that students can practice reading the soil texture triangle; examples are also given in the worksheet provided in the **Supplementary Material**. Students may be sent into breakout rooms to practice using the soil texture triangle with their peers; smaller groups promote greater interaction in the remote environment and give the students opportunity to work through challenges together.

When the class is ready to practice the two hands-on techniques, let students know that they have bags filled with different (unknown to them) soils. First, they will determine the soil texture using the "texture by feel" method. This method uses a flow chart to guide them as they examine the soil's physical properties. The texture names on the flow chart correspond to sections of the texture triangle. In the data table, students will record their best estimate of the soil texture for each unknown.

A useful prompt for the texture by feel method is to instruct students to wet a golf ball-sized subsample of soil to the point where it develops the same consistency as cookie dough. Students will then follow the instructions on the texturing flow chart to "ribbon" the soil between their thumb pad and side of index finger to assess its clay content. As they move through the flow chart, they will also explore the "grittiness" of the soil by placing a pinch of the soil sample in their palm, wetting it to a soup-like consistency, then rubbing their index finger on the surface to estimate sand content. They will also rub a small amount of wet soil between their thumb and index finger to assess "slipperiness" or "smoothness", the amount of silt in the unknown (see **Supplementary Material**).

Second, students will determine soil color by wetting a small amount of soil (approximately the size of a pea) in one hand or on a finger and matching it to the appropriate color in the Munsell color chart. Generally, color is reported with its "wet" value. However, if determining soil color and one does not moisten it, then it would be important to report the value as "dry". At this point, remind students that there are three components of color: *hue* (spectral color, the page), *value* (lightness or darkness, labeled vertically on each page), and *chroma* (intensity, labeled horizontally on each page). Students should record these three components of color in their data table. The combination of hue, value, and chroma corresponds to a color name (e.g., 2.5YR 6/1 is "reddish gray"). The color name is on the page of the Munsell color book opposite the color chip. The instructor can have the students write the color name for each unknown soil in their data tables. Smartphone applications will provide this information, as well.

Finally, students will interpret the observations that they have made about each soil to determine the soil's origin and make an informed guess about the environment in which that soil exists/the soil creates. This final part of the exercise provides an opportunity for them to synthesize their knowledge, integrating concepts from their pre-class reading, as well as the observations that they have made for each unknown soil. Potential prompts include:

1. Does the soil likely come from an oxidizing (aerated) or reducing (water-logged) environment? (Hint: consider the color.)
2. How well does the soil likely hold water? (Hint: think about the size of the soil particles and the likely pore structure of the soil matrix when it is in an intact soil profile.)
3. Where did the soil come from in the soil profile? On the landscape? Geographically?
4. If students use soils that they collected near their home that were not provided by the instructor, then have them describe to their peers the characteristics of the soils, and have peers generate informed guesses about each soil's origin.

Following a brief demonstration of the two hands-on techniques and explaining how to make their informed interpretations of each soil, students can complete the three activities in their breakout rooms. This part of the class takes $\sim$40 min, depending on the number of unknowns. In our experience, students enjoy working through the flow chart and comparing ideas within their small groups; while this is going on, the instructor and teaching assistants can move in and out of breakout rooms to answer questions, check techniques, and redirect students, if necessary.

When all groups have finished keying out the unknowns and completing the worksheet, bring the class back to the main room for a whole class report out. The instructor can go through each soil unknown one by one and ask students what texture and color they selected and their interpretations of the soil's origin. These discussions tend to be lively, and, because students have worked in small groups, they participate readily with the support of their peers. If students found an unknown to be particularly difficult to decide on color or texture, prompt them to explain why. Similarly, when they offer interpretations of each soil's origin, ask them to explain their logic using background information from their pre-class reading or knowledge of the local area. For example, "I think this soil came from the base of a slope in the Colorado Foothills. It has a high clay content that is likely from accumulation of clay particles at the base of the slope, and some grittiness, which is likely contributed from the weathering of granodiorite bedrock."

We recommend that students discuss their interpretations in small groups and fill in their data tables with the group's final answers. However, they should each turn in their own work and acknowledge their group members.

After the students have completed this course module, the instructor may decide to have them explore questions that prompt further thinking (see **Supplementary Material**) or reflect on their learning experience in class with a metacognitive (e.g., journaling) activity. Such an activity can be used throughout a course, not just for one class period, to prompt reflection and solidify new concepts. In addition, student responses can be useful to guide the instructor in developing future iterations of the course; for example, to improve upon approaches to teaching the techniques for their particular population of students. Potential prompts for the journaling activity include:

1. What was challenging about learning these techniques for assessing soil properties and why? What was easier than you expected and why?
2. If you were assessing soil color and texture in the field (as opposed to from a sample in a bag), what

additional information would you have that would help your interpretations about the soil?

Reflections and synthesis

When the COVID-19 pandemic forced us to explore effective remote approaches to teaching hands-on techniques for assessing soil physical properties, we made three primary changes to the in-person approach. The first was that we needed to be more flexible regarding the example soils that students use for the texturing and color analyses. Some could pick up our pre-prepared (and keyed) soil unknowns, while others were home in quarantine and had to obtain their own. The latter challenged our goal of creating equal opportunities for students to explore synthesis and have productive group discussions. It is important to note that this flexibility was out of necessity; prior studies have noted that increased flexibility in learning approaches does not necessarily lead to higher learning gains (e.g., Thai et al., 2020). Second, using platforms like Zoom provided an opportunity for easy movement between small-group (i.e., breakout rooms) and whole class work. Thus, we incorporated more specific prompts and thought-provoking questions to ensure that students used their small group time effectively, consistent with documented research on social learning theory (see Yates et al., 2021; Yang et al., 2022 and citations within). Finally, because we could not show students the hands-on techniques in person and assess their skill mastery, we developed clearer, more relatable descriptions of the success metrics to communicate verbally and demonstrate in our own Zoom windows (e.g., Yates et al., 2021). For example, describing the ideal moisture content of the soil for hand texturing as "like cookie dough". Ultimately, we believe, such specificity improves in-person teaching and skills acquisition, as well.

During many years of teaching this course module, we have identified areas where students tend to encounter challenges, regardless of the learning platform (in-person or remote). Common pitfalls for students include not thoroughly wetting soils for the texture by feel method, causing misinterpretation of dry aggregates as sand grains; over-wetting soils, which can cause soil to fall apart and clay content to be underestimated; or working with an insufficient amount of soil in their hands. In addition, when interpreting the soils' origins, sometimes students will choose an environment that does not have an upland soil, such as suggesting that an unknown with a "sandy" texture is from the beach. However, we have found that even in the remote learning environment, these issues are relatively easy to identify and correct as the instructor and/or teaching assistants are interacting with students. Ultimately, we find that between completing this course module, as well as subsequent opportunities to practice (e.g., a practicum to assess their techniques), students can master their skills in soil texture and color analysis. The students self-report such learning gains, as well, and contrast even a remote experiential learning approach with having benefits over more traditional, lecture-based courses. For example, one student reported,

> *Being lectured on the differences in the physical characteristics of soil would not nearly have been as potent or memorable as actually participating in identifying several soil properties and types.*

Another student described how hands-on learning—even in the remote environment—helped the skills stay with them. They wrote,

> *When I learned about how water moves differently through a loamy sand versus a silty clay, there was a memory of the different textures that I had felt during the lab. Being able to reference the textures in my head allowed me to better understand why different soils influence different hydrological processes.*

The focus of the course will determine the follow-up activities that an instructor will choose to do. In our experiences, we have situated this class activity in a variety of ways. For example, one could follow with demonstrating other, more involved laboratory-based methods of soil texture analysis, such as the hydrometer method (Gee and Or, 2002). Alternatively, students could be assigned to take a field trip individually or with a partner to practice the skills that they learned, document their observations, and present them to the class. Such self-guided field trips have been used effectively in undergraduate courses within several fields (e.g., Shinneman et al., 2020; Middlebrooks and Salewski, 2021; Schwarzenbach et al., 2022). Still further, the information and skills learned within this course module could provide the basis for more complex material, such as learning about fluid flow and soil chemical transformations. Instructors may consider offering a practicum to assess the four stated learning objectives, and to provide follow-up training sessions, if necessary.

Regardless of the course focus, this activity provides a novel way to engage students in learning field methods—including through remote learning platforms—and has the potential to inspire continued engagement in a range of environmental fields. We have had many undergraduate students who have completed our courses with hands-on modules like this one and gone on to pursue an independent research project, or to apply to graduate school. For example, one student reported,

> *Doing hands-on classwork directly impacted my ability as a student and strengthened my resume when searching for jobs. My learning style is more direct and hands-on. So, when the learning material was presented to me in an experimental approach, I could retain the information better.*

Still another attributed learning these skills to success going on the job market:

> *I directly used the soil texturing and coloring skills taught in the lab in my first field-based job out of college. First, the activity gave me a direct experience that I could reference in my interview. Second, I had a solid foundation to build on because the field methods in my job used the exact same protocols (flow chart, texture triangle, and Munsell color book) as the lab. This meant that it took less training and time for me to become proficient with the method in my job.*

The majority of students who have gained hands-on training to learn about soils have simply discovered for themselves that the world beneath their feet contains a tremendous amount of information about place, and it is worthy of attention, appreciation, and conservation. The ability to cultivate such perspective, regardless of the learning modality, provides instructors with promising approaches to positively influence students' experience.

Author contributions

E-LH and SF designed the educational activities, developed the course materials, and wrote the manuscript. Both authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2022.959776/full#supplementary-material

References

Bishop, J., and Verleger, M. A. (2013). "The flipped classroom: a survey of the research," in *Proceedings of the 2013 ASEE Annual Conference & Exposition*, Atlanta, GA.

Bonwell, C. C., and Eison, J. A. (1991). *Active learning: Creating excitement in the classroom. 1991 ASHE-ERIC higher education reports. ERIC Clearinghouse on Higher Education*. Washington, DC: The George Washington University.

Dang, N. V., Chiang, J. C., Brown, H. M., and McDonald, K. K. (2018). Curricular activities that promote metacognitive skills impact lower-performing students in an introductory biology course. *J. Microbiol. Biol. Educ.* 19, 19–11. doi: 10.1128/jmbe.v19i1.1324

Dunlap, J. C. (2006). Using guided reflective journaling activities to capture students' changing perceptions. *TechTrends* 50, 20–26.

Gee, G. W., and Or, D. (2002). "Particle-size analysis," in *Methods of soil Analysis*, eds J. H. Dane, and G. C. Topp, (Madison: Soils Science Society of America).

Hammond, J. C., Harpold, A. A., Weiss, S., and Kampf, S. K. (2019). Partitioning snowmelt and rainfall in the critical zone: effects of climate type and soil properties. *Hydrol. Earth Syst. Sci.* 23, 3553–3570. doi: 10.5194/hess-23-3553-2019

Johnson, R. T., and Johnson, D. W. (2008). Active learning: cooperation in the classroom. *Annu. Rep. Educ. Psychol. Japan* 47, 29–30. doi: 10.5926/arepj1962.47.0_29

Karaali, G. (2015). Metacognition in the classroom: motivation and self-awareness of mathematics learners. *Primus* 25, 439–452. doi: 10.1080/10511970.2015.1027837

Koh, J. H. L. (2019). Four pedagogical dimensions for understanding flipped classroom practices in higher education: a systematic review. *Educ. Sci.* 19, 14–33. doi: 10.12738/estp.2019.4.002

Love, B., Hodge, A., Corritore, C., and Ernst, D. C. (2015). Inquiry-based learning and the flipped classroom model. *Primus* 25, 745–762. doi: 10.1080/10511970.2015.1046005

McCabe, T. M., and Olimpo, J. T. (2020). Advancing metacognitive practices in experimental design: a suite of worksheet-based activities to promote reflection and discourse in laboratory contexts. *J. Microbiol. Biol. Educ.* 21:130. doi: 10.1128/jmbe.v21i1.2009

Middlebrooks, M. L., and Salewski, E. (2021). Self-guided field trips take invertebrate zoology students away from their screens and into the environment for hands-on learning. *Invertebr. Biol.* 140:e12325. doi: 10.1111/ivb.12325

Rasmussen, C., Heckman, K., Wieder, W. R., Keiluweit, M., Lawrence, C. R., Berhe, A. A., et al. (2018). Beyond clay: towards an improved set of variables for predicting soil organic matter content. *Biogeochemistry* 137, 297–306. doi: 10.1007/s10533-018-0424-3

Riener, C., and Willingham, D. (2010). The myth of learning styles. *Change* 42, 32–35. doi: 10.1080/00091383.2010.503139

Schwarzenbach, F. M., Seibert, J., and van Meerveld, H. J. (2022). Self-guided smartphone excursions in university teaching—experiences from exploring "water in the city". *Front. Environ. Sci.* 10:875712. doi: 10.3389/fenvs.2022.875712

Shinneman, A. L., Loeffler, S., and Myrbo, A. E. (2020). Self-guided field trips allow flexibility in undergraduate student introductory field experiences. *J. Geosci. Educ.* 68, 371–379. doi: 10.1080/10899995.2020.1768006

Soong, J. L., Janssens, I. A., Grau, O., Margalef, O., Stahl, C., Van Langenhove, L., et al. (2020). Soil properties explain tree growth and mortality, but not biomass, across phosphorus-depleted tropical forests. *Sci. Rep.* 10:2302. doi: 10.1038/s41598-020-58913-8

Thai, N. T. T., De Wever, B., and Valcke, M. (2020). Face-to-face, blended, flipped, or online learning environment? Impact on learning performance and student cognitions. *J. Comput. Assist. Learn.* 36, 397–411.

Towns, M. H., Kreke, K., and Fields, A. (2000). An action research project: student perspectives on small-group learning in chemistry. *J. Chem. Educ.* 77:111. doi: 10.1021/ed077p111

Weil, R. R., and Brady, N. C. (2016). *The Nature and Properties of Soils*, 15th Edn. London: Pearson, 1104.

Yang, T., Luo, H., and Sun, D. (2022). Investigating the combined effects of group size and group composition in online discussion. *Act. Learn. High. Educ.* 23, 115–128. doi: 10.1177/1469787420938524

Yates, A., Starkey, L., Egerton, B., and Flueggen, F. (2021). High school students' experience of online learning during Covid-19: the influence of technology and pedagogy. *Technol. Pedag. Educ.* 30, 59–73. doi: 10.1080/1475939X.2020.1854337

Zarestky, J., Bigler, M., Brazile, M., Lopes, T., and Bangerth, W. (2022). Reflective writing supports metacognition and self-regulation in graduate computational science and engineering. *Comput. Educ. Open* 3:10008. doi: 10.1016/j.caeo.2022.100085