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EDITED BY
Anne Elisabeth Bjune,
University of Bergen, Norway

REVIEWED BY
Karen L. Bacon,
National University of Ireland Galway, Ireland
Karen Gariboldi,
University of Pisa, Italy

*CORRESPONDENCE
Eric W. Dewar
edewar@suffolk.edu

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Teaching writing skills in online paleontology and evolution courses

Eric W. Dewar[1]*, M. Eugenia L. Gold[1] and Heather Dwyer[2]

[1]Department of Biology, Suffolk University, Boston, MA, United States, [2]Center for the Enhancement of Learning and Teaching, Tufts University, Medford, MA, United States

Though foundational knowledge and technical skills are frequently and rightfully emphasized in biology curricula, transferrable skills, including writing, are under-prioritized to the detriment of biology graduates and to the scientific field. In an effort to target this gap, we designed assessments in online paleontology and evolution courses to foster critical analysis, synthesis, and written communication skills among students. This article describes model writing assignments for a variety of college courses at different levels and for different audiences. For example, appropriate analysis and comparison of major texts like Darwin's *On the Origin of Species by Means of Natural Selection* can be approached by students in general education courses as well as upper-level science students within their major. In another assignment, upper-level science students write to assess the effectiveness of novel characters in phylogenetic systematics. Last, we describe an assignment that introduces students to paleoecological interpretation to develop expository writing skills for scientists and non-scientists alike.

KEYWORDS

online and higher education, scientific communication, evolution, paleontology, undergraduate college

Introduction

During the COVID-19 pandemic, the shift to primarily online interaction reiterated the need to make undergraduate science courses more accessible (e.g., Hsu, 2020; Theodosiou and Corbin, 2020). Outside higher education during this time, scientific communication came to light as a critical skill of professional scientists to promote the accurate science underlying public health measures (Porat et al., 2020). As scientists, our ability to communicate accurate and understandable information to other scientists and the public is a critical skill to be attained through a college science degree, one now garnering greater attention in proposals for curricular redesign (Dansereau et al., 2020). In the face of COVID-19, the problem faced by instructors at many institutions of higher education became how to teach those communication skills online (Reynolds et al., 2020).

There is a range of opinions as well as concrete proposals regarding curricula in biology departments (see Cheesman et al., 2001), but most of these curricula combine foundational knowledge and experiential or skill-based aspects to an aspiring biologist's training. The American Academy for the Advancement of Science's *Vision and Change* proposal (AAAS, 2011) included critical bodies of disciplinary knowledge to master (their Core Concepts), but just as important in their call to action are their Core Competencies of doing science. One of these competencies is the ability to communicate and collaborate with other disciplines. Here we focus on assessments that can develop students' ability to write to learn and to communicate their ideas to other scientists and the public.

Scientists and their work elicit a range of trust from the larger society (Funk, 2020). Whether the topic is evolutionary theory or public health measures, scientists are required to be able to communicate ideas from their disciplines in ways that are both accurate and approachable to non-specialists to counter the spread of misinformation or conspiracy theories endemic on social media (Nuffield Council on Bioethics, 2020). Both working scientists and student-scientists-in-training need to learn to communicate ideas clearly but simply, without being simplistic.

Developing the writing and communication skills of young scientists is programmed into many courses for their professional development; many students write at length about data observed in laboratory exercises, typically in the form of lab reports that enforce a characteristic structure of the typical Introduction–Methods–Results–Discussion format more suitable for a scientific audience than a lay audience. Since *Vision and Change*, departments across the United States (Harvey et al., 2016) adjusted curricula to provide more frequent opportunities for students to craft scientific arguments that require integration of ideas from the professional literature of biology.

The need for students to develop their ideas by "thinking out loud" in writing is one focus of the assignments we have developed. We wanted to give students the opportunity to practice writing arguments that synthesized their own insights with ideas from various sources from the professional literature of science. This synthesis represents a higher order of learning (Bloom, 1956) than merely reporting out data in a lab report. These assignments were also intended to support students' time in conversation with their peers by giving them the chance to find words to frame their argument before jumping into class discussion. Similar skills are needed to communicate scientific ideas to a lay audience so that they can connect new information with the initial scientific knowledge and conceptions of the public.

Hybrid vs. online courses

Even before the pandemic several modes of online courses had been developed. Though definitions vary, we define hybrid courses as ones that integrate a substantial online or technology-based delivery mode for class experiences in order to emphasize self-directed learning, i.e., a student's ability to regulate their own learning process (Garrison and Kanuka, 2004; McTighe and Wiggins, 2004; Caulfield, 2011; Graham, 2013; Linder, 2017). Many traditional face-to-face (F2F) courses use technology, but hybrid courses are intentionally designed to move most class activities away from a class's F2F meeting time and into a learning management system (LMS), blog, shared drive space, or other system for communication and feedback (Graham, 2006). Hybrid courses might meet in person for a third or a quarter of the time of a typical F2F course. The activities that happen in that F2F time will probably not be a typical delivery of a lecture, but more likely an activity that is better done in person than online, such as discussion, tactile activities, collaborative practice, etc. Fully online courses that universities largely depended on during the pandemic lost the F2F vs. online-activity distinction, but the writing assignments described here work for both.

What are the benefits of a hybrid course? The hybrid format permits us to make mindful decisions about how self-directed learning can be best facilitated and what activities should be done synchronously with students (Linder, 2017). Courses taught with this format introduce the same content and ideas that are included in traditional formats. Some courses, such as quantitative methods or disciplinary writing courses in a major, are well-suited for the hybrid format because they require substantial out-of-class work but less real "factual content." Skills-oriented courses like these can be successfully taught that in a hybrid format with little difference in student end-of-semester performance (Friedman and Friedman, 2011), and by many educational outcomes, performance in hybrid courses can even exceed F2F courses (Means et al., 2010). Furthermore, unlike fully online courses, students will still be able to have the humanized experience of interaction with their peers and the instructor in person (Bernard et al., 2009; Means et al., 2010; Abrami et al., 2011).

Outside the pandemic, the fully online course format might be most effective when it solves a scheduling problem for students such as the schedule of other courses or off-campus jobs or internships. A well-designed online course can allow students with different learning preferences to learn the content in a way that makes the most sense for their self-paced, independent learning, whether that means adjusting the speed on instructional videos, engaging in an online chat about

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difficult content, or pausing and revisiting the course material after tending to one's family (Bender, 2012).

The aim of this paper is to introduce three writing assessments applicable to courses throughout the biology curriculum for learning paleontology and evolution: (A) a close reading of Darwin's *On the Origin of Species* (Section 2 below); (B) construction of an evolutionary tree (Section 3 below); and C) the research and description of a geological formation (Section 4 below). These have been successful in general biology courses, upper-level and non-science-major courses about evolution, and in historical biology and paleontology courses. These assessments were developed to help students synthesize their knowledge with the professional literature, to collect trait data to develop a more rigorous understanding of phylogenetic systematics, or to characterize the depositional environments of fossil-bearing rock formations to develop a fuller vision of the lives and interactions of extinct species. All of these assessments help students develop the writing skills that are essential for practicing scientists to successfully communicate with others in and out of the profession, and all of them can be successfully executed regardless of course modality.

Close reading of Darwin's *On the Origin of Species by Natural Selection*

This assignment stems from two reading-and-writing-intensive courses developed for different audiences. One is a lecture-only course that outlines the main ideas of evolution for biology majors and the other is a general-education course taken by students from non-science majors as an introduction to scientific thinking through evolution, with a particular focus on how it plays out in our bodies, societies, and futures. One shared component of these courses is a close reading of the scientific literature and discussion of those papers' ideas with an eye to integrate those ideas with the students' existing knowledge to create a richer, more integrated whole.

In the course for biology majors (Evolution), we read *On the Origin of Species by Means of Natural Selection* so that they can experience Darwin's first (1859) complete formulation of evolution by natural selection and consider the range of modern developments since the nineteenth century. All biology majors will be familiar with Darwinian foundations of evolutionary theory and post-Synthesis developments such as comparative genomics, horizontal gene transfer, and the single tree of life, but few undergraduates have read Darwin's landmark book. A writing-intensive course design can be a high-impact educational practice (Kuh, 2008), particularly when junior and senior-level students can write to learn within their discipline (Zinsser, 1988; Bean, 2011). For each reading assignment, the student composes a response of about 750 words that are graded with a rubric through the learning management system (LMS). The full student instructions and grading rubric for the assignment are found in **Supplementary material 1**. The primary outcome of this assignment is for the student to elaborate upon their understanding about Darwin's ideas as well as synthesize or integrate it with more recent research that they chose to compare it with.

The course is oriented around a close reading of the *Origin* for several reasons. The "classic papers" approach to teaching college science is well-established (e.g., Kiang et al., 2015), and the *Origin* was ranked third-highest of books that influenced the careers of the professional biologists surveyed by Barrett and Mabry (2002). Nearly all biology majors learn about Darwin and his ideas, but few have read his most important work for themselves. Darwin's scientific process and his deployment of facts from the natural world is timeless in a way that is very different from today's understanding of ecology or molecular biology. The *Origin* is quite approachable by undergraduates once they get used to Darwin's writing voice; it was intended for a lay audience at the time of its publication (Ruse, 2008), and students become interested and engaged with the text. Evolutionary biologists can demonstrate and model the scientific process—including how our ideas change in the face of new evidence or more parsimonious interpretations—by reading the *Origin* and synthesizing Darwin's ideas with modern biological knowledge.

In the evolution course, we encourage students to read the first edition of the *Origin*, because it is Darwin at his "darwiniest," i.e., representing the core of his thinking and intellectual contributions, and because numerous free or low-cost editions exist of the book in both electronic and paper formats. On the other hand, for students challenged by Darwin's writing style, a more modern voice is provided by the "English translations" of the sixth edition in Jan Pechenik's *The Readable Darwin* (Pechenik, 2014) or Daniel Duzdevich's *Darwin's* On the Origin of Species*: A Modern Rendition* (Duzdevich, 2014). Reading of any edition is accompanied by a multi-part assignment.

Part 1: Find one new insight

The first part of this exercise is to allow students to explore Darwin's ideas with an eye to find and elaborate on one new insight from the assigned section. That section is usually a chapter of the book covered each week, but we do combine the chapters of geographic distribution to account for the length of the semester. They are instructed to lead their response with their new insight as a one-sentence abstract. An "insight" could be a turn of phrase that crystallized the chapter's topic in some new way for them; or they might identify an idea that Darwin had that we now know is wrong; or they might choose to explore an interesting question identified by Darwin that is still an open topic of scientific curiosity and exploration. This stage of the reading emphasizes the comprehension and evaluation levels of Bloom's (1956) taxonomy of learning. The nature of a "good insight" is kept intentionally broad; by giving students the maximum latitude to make decisions about their learning and encouraging a high level of dialog with the instructor (and their peers), they can decrease the transactional distance between them and the instructor (Moore and Kearsley, 1996), further humanizing an online course experience.

Once the students have identified their insight, the second part of the assignment is to seek out related research on that same topic from the primary literature of the last five years to gauge scientists' current perspectives. Comparing and integrating these works separated by more than 150 years engages higher levels of thinking, including Bloom's (1956) synthesis level. Upper-division students can explore the relevance of evolution to their main interests in biology, be it related to human health, the microbiome, a model organism, marine conservation, or any other area of study.

Part 2: Sharing related articles

The hybrid or online environment facilitates the sharing of resources and ideas. For each chapter in the *Origin*, students uploaded citations and copies of the papers that they found and chose to relate to the *Origin* on a wiki page on the LMS. Each student must choose a unique paper, so as the semester progresses, the wiki pages develop into a "further reading" appendix to the *Origin* culled from the recent literature of evolution, with direct links to PDFs. Over the course of the semester in a 40-person class, this can translate to more than 500 recent articles that one could pull from later. Their related papers are posted to the LMS about 3–4 days before the response is due, and responses must be submitted by the start of the F2F meeting time, so the work of their reading, contemplation, synthesis, and writing is broken up into manageable steps before the group discussion takes place.

Part 3: Exchanging ideas with peers

The majority of the F2F or synchronous meetings in this course are centered around discussing their responses to the week's readings with occasional brief lecturing about critical new or confusing content. During discussion meetings, everyone in the class has read the same section of the *Origin*, but because they all chose different follow-up papers based on their various interests and insights, no one has synthesized it with the same recent topic of research. The format and progression of discussion varies from week to week. Early in the semester, we start by emphasizing Darwin's logic of thinking in the "process" part of his book and contrast the natural history information available to him with what is known by most undergraduate biology majors today. As the course progresses, students become more comfortable with presenting their ideas and responding to their peers. As we move to Darwin's answers to "miscellaneous objections" in Chapter 7 or the "pattern" section of the latter parts of the book, the discussions become more freeform; students take the lead with what they thought was notable and how it connected to other upper-level courses that they had taken, such as biochemistry, microbiology, or animal behavior.

The *Origin* assignment for non-science students

A more streamlined version of this assignment is used for Humans and the Evolutionary Perspective, a general-education evolution course for non-science students. In this case, students read the "Natural Selection" chapter of the *Origin* to get a flavor of this first articulation of Darwin's theory, but also articles or book chapters about a range of evolutionary questions with applicability toward aspects of human nature, such as the evolution of skin coloration (Jablonski and Chaplin, 2010), menopause (Leidy, 1999), memes (Dawkins, 1976; Blackmore, 2000), beauty (Prum, 2017), sleep (Nunn et al., 2016), or disgust (Curtis et al., 2011). Given a group of students with less pre-existing knowledge about evolutionary ideas, they are not required to relate these readings to professional literature; their task is to find one new insight from the reading but to relate that insight to something from their lives, their studies, or the news. These 500-word responses are sufficient to allow then to develop their ideas to a degree that everyone has something to contribute to the class discussion.

Understanding how evolutionary trees are built

One of the goals of a paleontology or evolution course is to understand the major patterns in the history of life (Gregory, 2008). Because modern evolutionary biology prioritizes "tree thinking" in evolutionary patterns, one of the major objectives of evolution courses is to build phylogenies using trait observations and phylogenetic software. Upper-level biology majors will have seen evolutionary trees in their introductory texts, but few will have made phylogenetic hypotheses of their own from data that they observed first-hand on natural history specimens. The project of constructing phylogenies was divided into (1) observation of trait data; (2) construction of their own evolutionary trees; and (3) written analysis about the "effectiveness" of their characters. The result of the project is to hypothesize evolutionary relationships among 15 living and fossil vertebrates (with an arthropod outgroup) using 25 characters, and to reflect in writing about the effectiveness of their observations to recover clades within the taxa.

Part 1: Observation of trait data

The first part of this project happens early in the semester. The group takes a field trip to observe the traits of animal taxa at the Harvard Museum of Natural History (Cambridge, MA), which is the closest large natural history museum from our campus in downtown Boston. Most of our students are interested in biomedical science, but few of them will had had any experience in laboratories in comparative biology, so this an opportunity for them to practice observing non-experimental data that are used to test hypotheses.

The lecture narrative of the course starts with early ideas about Linnaean trait homologies and evolutionary relatedness that fed into Darwin's initial formulation of natural selection, so students make observations of a morphological level by recording traits of animal species on display, primarily gross features of the skeleton. The taxon and character lists are found in **Supplementary material 2**. Animal taxa were chosen because most biology majors and non-science students are inherently more familiar with general animal groups than plants, fungi, or bacteria. Even among students with mixed levels of experience with biological diversity, there has been a trend of decreasing coursework about natural history in US colleges and universities (Middendorf and Pohlad, 2014). The traits of animals (and particularly vertebrates) are close enough to home that they can be effective at identifying and choosing traits, even for students who have only completed introductory-level courses before taking this evolution elective. On the other hand, Czekanski-Moir and Rundell (2020) make a strong case for using invertebrate groups for such activities, as a way to help students to place themselves in the tree of life, to appreciate some of the diversity of life away from humans' closer relatives, and to avoid the false impression of evolutionary change being synonymous with "progress." No one list of taxa will be represented in every natural history museum's exhibits, but the instructor can customize taxon lists of similar diversity for the displays at any natural history museum.

Because of the large self-learning aspect of a hybrid or online course, a field trip like this allows some rare full-group time with our students to facilitate group cohesion and camaraderie. When the hybrid class runs with a larger enrollment of 30–40 students, they will not interact with every other student in the F2F meeting time. Even when the course is smaller, students will mainly interact with their peers through the LMS for much of the course. This in-person meeting helps to connect discussion board names with real faces, and help to humanize the experience of the course, which then promotes online interactions that can be critical of ideas while being constructive and kind. An accessible but less interactive alternative to this field trip could be to curate a collection of websites or a museum database with photographs of collections of these taxa so that the students could make observations from those resources rather than viewing specimens in person.

The process at the museum was somewhat iterative: 15 of the characters and 10 of the taxa were assigned and the remaining four mammalian taxa and five characters were chosen by groups of students. First, the students in groups of two to four set out to find specimens of the required species on display and score the list of 15 character traits provided in the assignment. The required characters were selected for their ability to serve as synapomorphies that would discern clades like Tetrapoda, Amniota, Dinosauria + Aves, Mammalia, etc. Once that was completed, each group chose four species from one mammalian order on display. It was expected that most of these mammals would be identical (or nearly so) in regard to their required characteristics (intended to identify higher-level relationships), so each group had to come up with five new traits that could be used to nest the species within the order that they chose. The last step of the observational phase was to go back to the required taxa and score them on their five new characters based on the mammal species that they chose.

Part 2: Construction of their own evolutionary trees

Turning data matrices into trees is a little complicated for students who do not have any experience with systematics software or programming. Some of our students will have had some introductory programming experience in R (R Core Team, 2021), but none are likely to have used phylogenetics packages such as *ape* (Paradis et al., 2004) written for R. A more user-friendly alternative is the stand-alone freeware package Mesquite (Maddison and Maddison, 2021). In class, the students have a guided walk through a workflow of entering data with a script of functions, and for the real beginners, videos are posted of entering the data to the interface and working the analyses. The best-supported trees based on their observations were the ones with the shortest branch length and highest retention index. The feedback to students includes explanations of which traits proved to be good synapomorphies for clades and which were not a useful to define natural groups of species.

Part 3: Written analysis about the "effectiveness" of their characters

The purpose of the write-up for this assignment was for students to assess which of their characters made for good synapomorphies. A three-part format for the paper is recommended, with Introduction, Methods, and combined Results + Discussion sections. The students are guided through reviewing the steps of the group's project, first by discussing the resulting tree and then helping them to identify the traits or characters that were successful or problematic for defining clades. Each student writes a paper in which they process the relative success of their work to define clades using the traits that they chose in comparison to a reference tree found in a textbook.

All students who scored their observations correctly should have recovered a "reasonable" tree topology for the vertebrate classes, but most will have more stumbling blocks with their new characters. Often characters that "made sense at the time" to hypothesize relationships within their selected family of mammals were found to be more superficial, homoplastic, or non-homologous with the traits of the "required" taxa. Biological homology and tree thinking are fundamental to understanding how evolution has sculpted biological diversity. Students took away a better understanding of the comparative, phylogenetic approach by taking an experiential-learning assignment (Erickson and Strommer, 2005) in which they gathered and processed their own data within specific guidelines and had time for reflection in writing.

Adopt-a-Formation project

The writing-to-learn approach was taken in a paleontology/historical biology course to allow biology majors to learn to apply basic concepts in fossil deposition and erosion. We created a project for the course "Earth and Life Through Time" that specifically works to bolster their nascent communication skills in paleontology.

Over the duration of this upper-level major elective course, the students first learn foundational geological concepts like the principles of geology, sedimentology, and fossilization. We then take the students through the biological and geological changes that the Earth experienced from the beginning of our solar system to present day. The course incorporates traditional lectures with small group activities, and folds in freely accessible media (online PBS/YouTube video specials) on relevant topics to further engagement and understanding. The students write short (500 word) reflective papers to unite the course material with the topics covered in the videos. These smaller written assignments serve as practice for the culminating project in the course, the Adopt-a-Formation Project.

A few weeks into the course students chose a geologic formation to study from a list of fossiliferous formations that was curated by the instructors. Students chose to study a given formation for a variety of reasons: the formation was close to their hometown, somewhere they visited, or just sounded exotic. Over the rest of the semester, the students researched several aspects of this formation, including its lithology, age, fossil taxa represented, distribution and paleogeography, paleoenvironment and paleoclimate, and interpret a modern analogue. The processes behind each of these aspects are covered in the course's lectures, so the students have the foundation they needed to understand primary literature sources that they need to access and interpret. A list of formations chosen for an earlier semester and the assignment sheet is found in **Supplementary material 3**.

We built in several check-in assignments to ensure that they are making steady progress in this research, such as a bibliography, outline, and rough draft. The students also had a chance to practice their oral presentations before giving it to the students. The final product is a ∼1000-word paper with at least five cited papers and a slideshow presentation that all the aspects of the paper enumerated above.

This project allowed students to connect the geological and paleontological processes covered in the lectures to a tangible geological formation, build further context on geology they encountered in the course or their travels, and improved their ability to research and write about a scientific topic that was new to them. Given the time spent on this project and each of the assignments leading up to it, it was rewarding to hear from the students that it was one of the most enjoyable aspects of the course.

Best practices for teaching writing online

Many of the techniques instructors use to encourage curiosity, participation, and content mastery translate well to the hybrid or online course, but some are particularly critical for establishing and maintaining connection with students. Teaching these courses, we struggled the most with the social distance within the group (see Snart, 2010) and fatigue of online meetings. What follows are some recommendations for instructors looking to teach hybrid or online courses that foster writing and communication skills in students.

Set up a regular weekly calendar of activities and keep your promises

This includes establishing norms of regular communication that define the social presence of the course and help to keep its momentum. When a class only meets once a week, it can easily drop to the bottom of everyone's list of priorities, including the instructor's. We recommend that all course announcements are e-mailed to students or sent as push messages to their smartphones or using an online communication and distribution application. There is no best way to communicate with students; they will have their own preferences for convenience and private spaces and the options for communicating with them will change as new apps develop. Try new ways to communicate within the group without being overly intrusive (in either direction!) but find some communication mode that is workable and stick with it for the semester to avoid leaving some students behind.

Schedule specific times during the week for interactions with students through the learning management system

Schedule at least one "midweek" activity to keep the class in the front of their mind and to keep the students involved. This helps to keep the momentum of the course moving in the right direction. Keep all of these activities relevant to the goals of the course to avoid the appearance of busy work.

Plan a field trip or other course-related group activity early in the semester

The beginning of the semester allows students to get to know each other in a semi-structured social setting, but it might also work to have it as a summative end-of-semester activity as well. Depending on the time of year and what's available locally, it might be feasible to make a trip to some open space that will allow observations of living things in naturalistic environments. If converging independently on an off-campus location, consider adding time for food afterward to increase the social cohesion, whether it's a meal or just an ice cream together with the group.

Build in collaborative interactions that model modes of communication

If a goal of the course is to learn to collaborate on shared documents, then a wiki could be a good option (Section 2 above, see also Barrera, 2015). For example, the instructor could set up the set of topics and the "skeleton" of each page of the wiki and the students could be responsible for contributing the content. A group of three to four students could take turns in an iterative process for each entry. Each entry requires similar tasks: (1) writing the first draft, (2) checking and elaborating on citations and online resources, and (3) further editing to connect to other pages on the wiki. First, each student would be assigned the first writing task for one of three pages. Next, each student would go to a second page to do the elaborations. Last, each student would move to a third page to do the further editing.

Developing scientists need to become effective communicators of their disciplines because laypeople need to understand the meaning and relevance of their ideas. An effective hybrid or online course can promote that outcome by giving students multiple opportunities to think out loud in writing. Courses that include several evidence-based pedagogical techniques have been shown to increase equity in STEM (President's Council on Advisors for Science and Technology, 2012). What we presented here were three assessments that encouraged and developed scientific synthesis and writing in students at different levels of expertise. Our recommendations above were intended to describe practices that were successful (measured *via* informal student feedback) and to make the assessments available to other instructors. Learning the style and form of effective scientific communication requires both solitary time for the writer as well as collective time for students to give and get feedback. This path is achievable in online and hybrid courses about paleontology and evolution across many levels of student experience.

Data availability statement

The original contributions presented in this study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author.

Author contributions

ED designed the evolution courses described here and co-designed the paleontology course, conceived of the manuscript, and wrote the manuscript. MG co-designed the paleontology course with ED and edited the manuscript. HD gathered literature and edited the manuscript. All 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.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2022.876875/full#supplementary-material

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