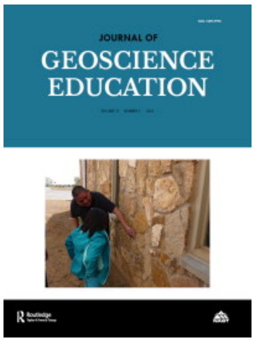

Routledge
Taylor & Francis Group

Journal of Geoscience Education

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/ujge20

Patterns in student self-reported situational interest in online introductory geoscience labs during COVID

Kelsey S. Bitting, Katherine Ryker & Rachel Teasdale

To cite this article: Kelsey S. Bitting, Katherine Ryker & Rachel Teasdale (06 Jun 2024): Patterns in student self-reported situational interest in online introductory geoscience labs during COVID, Journal of Geoscience Education, DOI: 10.1080/10899995.2024.2359318

To link to this article: https://doi.org/10.1080/10899995.2024.2359318

JOURNAL OF GEOSCIENCE EDUCATION
https://doi.org/10.1080/10899995.2024.2359318

Patterns in student self-reported situational interest in online introductory geoscience labs during COVID

Kelsey S. Bitting[a], Katherine Ryker[b] and Rachel Teasdale[c]

[a]Department of Environmental Studies, Elon University, Elon, North Carolina, USA; [b]School of Earth, Ocean, & Environment, University of South Carolina, Columbia, North Carolina, USA; [c]Department of Geological & Environmental Sciences, University of California, Chico, California, USA

ABSTRACT

Triggered situational interest in introductory courses can encourage student engagement, motivation, and value for the geosciences. In-person labs have traditionally played a unique role in triggering situational interest compared to lectures, but the COVID transition online disrupted these dynamics. We examine students' self-reported situational interest from 6,463 responses to weekly surveys in online introductory geoscience lab courses at five U.S. institutions during fall 2020 and spring 2021. Approximately half of students reported that labs were equally (49.4%) or more interesting (4.3%) online, compared to a hypothetical in-person option. Analysis showed a statistically-significant interaction between student situational interest and the combined effect of 1) the course the students were enrolled in and 2) the topic of the lab session ($F\ (20,\ 6395) = 4.038$, $p < 0.001$). However, topic and course together explain only about 4% of the variance in the dataset, indicating that other factors have a large role in triggering interest. Students who indicated that labs were less interesting online (46.3%) most often cited not being able to physically interact with instructional materials (56.3%) and difficulty interacting with peers (30.6%). When asked what revisions would increase their situational interest, additional hands-on interaction (22.8%) and increased relevance to their life or future career (20.2%) were the answer choices students selected most frequently. These findings identify modifications and enhancements grounded in students' self-reported interest that can inform the design of online introductory geology labs.

ARTICLE HISTORY
Received 31 August 2022
Revised 24 April 2024
Accepted 20 May 2024

KEYWORDS
Situational interest; online instruction; introductory course; laboratory course

Introduction

Like other STEM disciplines, introductory laboratorys (labs) serve an important role in the geology curriculum at U.S. higher education institutions. Traditionally, labs are where students engage in hands-on activities that support their learning. At larger universities where lectures may enroll hundreds of students, labs provide a small-class context in which to engage in group work and interact with the lab instructor (Luft et al., 2004; Park, 2004; Sundberg et al., 2005).

Post-COVID, moving or keeping labs online may help mitigate classroom maintenance costs in an era of declining enrollments (Grawe, 2018). Instructors might prefer teaching online classes to eliminate their commute (Badaru et al., 2022), manage the "two-body" problem (Wolf-Wendel et al., 2004), or attend conferences or conduct field work mid-semester. Some students may also prefer flexible online courses that minimize conflicts with work or family obligations (Beldarrain, 2006).

However, decisions related to course modality should also be informed by a thorough analysis of the strengths and weaknesses of different instructional modalities for facilitating different outcomes. Previous work has shown student satisfaction ratings are comparable between in-person and online labs (Faulconer & Gruss, 2018), but when asked, most students preferred a combination of online and face-to-face activities (Salter & Gardner, 2016). In one COVID-era study, students said the lack of in-person interaction with peers and faculty in online-only labs hindered their learning (Colthorpe & Ainscough, 2021), while another showed that students during COVID rated online courses more negatively than in-person ones (Price Banks & Vergez, 2022). Therefore, students' preferences for lab course format may be contextually dependent.

In terms of learning outcomes, a 2018 review determined that online, remote, and distance science labs were all equally as effective as in-person labs at helping students achieve course learning objectives (Faulconer & Gruss, 2018). This finding is consistent with analyses of content learning or summative assessment performance (Ayega & Khan, 2020; Colthorpe & Ainscough, 2021; Rowe et al., 2018; Thompson & Henson, 2021). However, face-to-face labs may more effectively support students' growth in practical and procedural skills (Faulconer & Gruss, 2018).

Affective outcomes such as attitudes and combined cognitive-affective outcomes like interest have drawn increased attention recently (McConnell & van Der Hoeven Kraft, 2011; van der Hoeven Kraft, 2017; van Der Hoeven

CONTACT Kelsey S. Bitting kbitting@elon.edu Department of Environmental Studies, Elon University, 2625 Campus Box, Elon, NC 27244, USA.
Supplemental data for this article can be accessed online at https://doi.org/10.1080/10899995.2024.2359318.

Kraft et al., 2011). Due to its role in motivational processes, interest has been shown to enhance learning, increase recruitment and retention, and promote non-majors' value for the geosciences (Gasiewski et al., 2012; Gilbert et al., 2012; LaDue et al., 2022; Lukes & McConnell, 2014; van der Hoeven Kraft, 2017). Therefore, developing students' interest should be considered an important goal of the introductory geology lab curriculum, alongside fostering conceptual learning.

A theoretical framework for interest

Interest is defined as cognitive and affective engagement with an event, activity, or content (Hidi & Renninger, 2006; Renninger & Su, 2019). Interest may develop through four phases (Hidi & Renninger, 2006; Renninger & Hidi, 2016; Renninger & Su, 2019). In the initial stage, *triggered situational interest*, a person's interest is sparked (perhaps fleetingly) by a stimulus, resulting in a primarily affective response. If situational interest triggers are repeated or sustained, a person moves into *maintained situational interest*, which includes learning and valuing content. If that person finds additional personal connections to the content or experience and begins seeking to reengage with it, but still requires some support to do so, interest moves to the *emerging individual interest* phase. Finally, *well-developed individual interest* is characterized by independent and persistent reengagement with that content. Repeatedly triggering or sustaining situational interest leads to increased individual interest and further engagement in related activities (Palmer et al., 2017; Rotgans & Schmidt, 2017).

As interest develops, students put more effort into learning, set their own goals, and apply increasingly sophisticated self-regulation strategies (Hidi & Renninger, 2006; Renninger & Hidi, 2016; Renninger & Su, 2019; van der Hoeven Kraft, 2017). These outcomes can enhance students' academic success, including enhancing students' value for knowledge and experience in the field (Hidi & Renninger, 2006), which may translate to taking future courses, declaring a major or minor (Harackiewicz et al., 2000, 2002, 2008; van der Hoeven Kraft, 2017), or seeking out related information when making personal decisions. Situational interest can be triggered for anyone (Crouch et al., 2018; Durik & Harackiewicz, 2007; Renninger & Su, 2019), but triggers may be most important for learners at the initial stages of interest development (Durik & Harackiewicz, 2007; Renninger & Su, 2019).

In our study, we examine whether and to what degree online introductory geology labs trigger situational interest (hereafter referred to as "interest"), and what features of the lab activities acted as triggers.

How might labs trigger interest?

Each lab activity offers an opportunity to trigger interest, and a wide range of design features or characteristics of instructional activities might act as effective triggers. Interest triggers are typically features in the environment, such as people or situations (Hulleman et al., 2008; Mitchell, 1993; Palmer, 2009; Palmer et al., 2016). Instructional features that are likely to trigger interest include active learning (van der Hoeven Kraft, 2017; Yuretich et al., 2001), student freedom and choice to shape the curriculum (Alexander et al., 1997; Renninger et al., 2015; van der Hoeven Kraft, 2017); recognition of the utility of academic content (Hulleman et al., 2017; Hulleman & Harackiewicz, 2009; Renninger & Su, 2019); societal relevance (Pelch & McConnell, 2017; Teasdale et al., 2018a, 2018b); novelty or discrepancy, such as when students are surprised by the outcome of a demonstration (Lin et al., 2013); topics associated with danger or that otherwise activate an emotional response (Schank, 1979; Wade et al., 1993); integration of art or aesthetics into science learning, such as demonstrations or hands-on experiments (Lin et al., 2013); well-scaffolded scientific inquiry (for novices, in particular); humor (Bergin, 1999; Machlev & Karlin, 2017); and social interaction (Bergin, 1999; Bertsch et al., 2014; Lin et al., 2013; Maltese & Harsh, 2015; Palmer, 2009; van der Hoeven Kraft, 2017). Additional features that may trigger interest include hands-on interaction, food, modeling, specific topics, biophilia, fantasy, and narrative (Bergin, 1999). If students perceive a lack of support in the learning environment, lack opportunities to find personal connection to the content or activity, or believe that their ideas are not being heard and respected, interest may drop or disappear (Bergin, 1999; Renninger & Hidi, 2019; Renninger & Lipstein, 2006; Renninger & Su, 2019).

Several factors have been investigated for their impact on children's interest in the geosciences. Trend (2005) found that British 11–12-year-old children were interested in major geological events and change over time in the past, with boys more interested in catastrophic events and girls more interested in societally-relevant environmental changes and things they envisioned as aesthetically pleasing. In tracing the career choice process for field geologists, LaDue and Pacheco (2013) found that family trips and the geology of those locales played a key role in developing their interest. Finally, stop-motion animations of plate tectonic processes significantly increased middle-school students' interest in learning geology compared to a traditional lecture (Mills et al., 2020).

Within the higher-education geoscience course context, additional interest triggers have been identified. For example, student interviews and surveys from a large oceanography lecture course suggested that cooperative learning, inquiry-based activities, and student projects or investigations increased interest in science for most students (Yuretich et al., 2001). In another study, a place-based, active-learning mini-unit resulted in small increases in science interest overall, but decreased science interest for community college students identifying as Hispanic/Latinx, Black, or Asian (Davies et al., 2023). A quantitative survey study of undergraduate geology majors in South Africa showed that field trips further enhanced their interest in geology (Hoyer & Hastie, 2022).

In the introductory geology lab context specifically, Grissom (2014) measured interest in in-person lab activities (segments of lab class sessions) at a large public university in the U.S. At the end of the semester, students were asked to identify the most and least interesting lab activities and explain their rankings. Open-coding of student explanations identified relevance to their lives or real-world application (40.0% of responses), followed by hands-on activity (18.9%) and that an activity was fun or like a game (18.9%). Additional characteristics students noted included working in groups, competitive activities, and high levels of scientific inquiry (Grissom, 2014). When describing why an activity was *not* interesting, students pointed to tedious or repetitive tasks (40.2% of responses), hard or confusing activities (38.6%), activities that they perceived to be irrelevant (18%), and activities that were not hands-on (3.2%). Interest ratings of individual lab activities were significantly correlated with opportunities for students to engage in scientific inquiry (Grissom, 2014). Grissom's approach served as inspiration for elements of this study.

Based on the studies reviewed in this section, situational interest can be triggered by a wide array of features or events that could be included in labs. Active learning, social interaction and support among peers, near-peer support from teaching assistants (TAs), hands-on manipulation of rocks, minerals or models, and novelty in the form of field trips fit well in lab sections of 20-25 students meeting for a few hours at a time.

What might be unique about interest in online labs during COVID?

The onset of COVID-19 led many spring 2020 introductory geology labs to shift to online formats. Online and hybrid instruction persisted for several subsequent semesters, depending on gathering size restrictions, local COVID caseloads, or other institutional policies. The broader context of the pandemic may have impacted students' interest in online labs in several ways.

Self-efficacy theory (Bandura, 1997) suggests that the isolation students experienced likely impacted their motivational state. Accessing peer-to-peer and TA support in online courses may have felt as though it required additional effort (unmuting oneself in a virtual class meeting to ask a question, turning on one's camera, or crafting an email to the TA) over and above simply turning to a neighbor, overhearing other students or the TA in class, or waving down a passing TA in the classroom. Lack of social support and loneliness are also associated with depression (Wang et al., 2018), which by definition includes loss of interest (American Psychiatric Association, 2013). College student mood and mental health did, in fact, diminish during the pandemic (Copeland et al., 2021; Wang et al., 2020).

Students likely experienced a form of mental exhaustion called "Zoom fatigue" in synchronous online class meetings (Nesher Shoshan & Wehrt, 2022), potentially reducing their susceptibility to interest triggers. Students likely engaged in positive mental contrasting (Appel et al., 2016; Verduyn et al., 2017) during the imposed limitations of the COVID pandemic, imagining how their courses could have been better under ideal circumstances.

During the emergency transition to online course formats in spring 2020, STEM instructors may not have had time or capacity to redesign labs for the online environment, and many prioritized supporting student belonging and responding to emergent student needs (Manierre et al., 2022; Thacker et al., 2022). Summer 2020 offered time for professional development, support, and guidance to help enhance online teaching for the fall. For example, our project convened geoscience faculty at the July 2020 virtual Earth Educators' Rendezvous conference to create 13 new guided inquiry labs for introductory geology courses, many of which were tailored to an online context (Teasdale et al., 2021a). Labs in this collection have, on average, higher inquiry levels than the average instructor-created lab (Teasdale et al., 2021b). Once implemented, preliminary data suggests that faculty did not alter online labs significantly over the following 2-4 semesters of use (Piper et al., 2022).

Another COVID-specific factor that may have impacted student interest is their lack of choice in course format. Choice helps to trigger interest (Alexander et al., 1997; Renninger et al., 2015; van der Hoeven Kraft, 2017) and autonomy is crucial to support its further development (Renninger & Su, 2019). However, government restrictions on gathering sizes and university policies regarding instructional modality during the pandemic meant that many institutions did not offer in-person lab classes, and those that did may have been forced to move online occasionally due to temporarily high caseloads or TA illness. Therefore, students could not choose their instructional modality, which may have undermined their interest.

Study aims and research questions

After the pandemic, with so much online course content already developed and ready for use, instructors may wonder whether online lab courses are working and how to improve them. The COVID emergency transition suddenly increased the number of online labs, creating an opportunity to rapidly collect a large dataset of student interest in this context. In this study, we analyze weekly survey data from a five-institution study of student self-reported situational interest in online introductory geology labs during the fall 2020-spring 2021 semesters to address the following three research questions:

1. What are students' average interest ratings for online introductory geology labs on different topics? In different courses?
2. How does student interest in online labs compare to a hypothetical in-person lab option, overall and for each topic?
3. What design features do students indicate influence their situational interest in online labs?

Our dataset offers insights that may help instructors refine existing online labs and inform administrative decisions regarding ongoing or expanded use of online labs in the future.

Methods

Study setting

Participants were students enrolled in introductory geology laboratory courses that included online labs (completed without face-to-face instruction) at five public research universities (denoted as C, I, N, S, and T) from across the U.S. in fall 2020 and spring 2021. The structure of the study is illustrated in Figure 1. We define "lab course" as a set of sections overseen by one instructor with primary decision-making power (selecting or writing lab activities and supervising teaching assistants). Each section enrolled 15-25 students and was taught by a graduate student teaching assistant (TA). "Labs" include all instructional materials and activities used in the lab period. Students in all sections of a course completed the same weekly labs.

At one institution (Univ. I), two instructors taught separate courses (courses I1 and I2) in physical geology and environmental science (Figure 1). A second institution (Univ. T) included lab sections associated with two separate courses that were combined during analysis because they were taught by the same instructor and more than half of the lab activities were shared. The other three institutions included one course each, resulting in a total of six lab courses in our study per semester.

In each semester, the lab course instructor selected two to three guided-inquiry labs designed in the workshop described above (modifications permitted), except for institution S which was used as a comparison institution that adopted none of the guided-inquiry labs (Figure 1). Beyond this detail, there was no shared curriculum, and each course covered different topics (Table 1), likely in different ways. Similarly, TA responsibilities and training varied by institution. Some courses were conducted online for the entire semester, while others met in-person for some labs or sections and online for others as local conditions varied. Rather than seeking to determine the impact of a single curriculum or instructional approach, our analysis examines lab features that students suggest influence their situational interest in online introductory geoscience labs in general. Only survey responses corresponding to online labs were included in the analysis.

Instrument design and data collection

Interest has been measured in a variety of ways (see Methods Supplement for more details). Grissom (2014) used a single-item design in which students marked a spot on a 10 cm line from "not at all interesting" to "very interesting" for each lab activity. This design simplifies the construct of interest but allows students to efficiently answer the item immediately after completing each activity (Grissom, 2014; Knogler et al., 2015; Little, 2023).

In our study, students were asked to complete weekly interest surveys modeled after Grissom's (2014) single item but using a four-point Likert scale (as used by Sherman-Morris & McNeal, 2016; Table 2) from "not at all interesting" to "very interesting." Students were also asked their name and school ID, their TA's name, the lab format (in-person, online as planned, online but originally planned to be in person), how interesting they believed each online lab activity was compared to a hypothetical in-person option, and any comments about the lab. Based on initial findings that many students thought labs were less interesting online, we added two questions (Table 2) to five institutions' surveys in spring 2021 (the sixth was not altered due to logistics). First, we asked students who said the online lab was less interesting than it would have been in person, "why?," with answer choices based on student comments from fall 2020: difficulty interacting with the instructor, difficulty interacting with peers, and an inability to physically interact with instructional materials like rocks, minerals, and maps (Table 2). We also asked which revisions could make their interest go up by 1 point, with answer choices derived primarily from Grissom's (2014) findings: increased relevance to their lives or future careers, engagement in authentic scientific processes, local field trip to see concepts in the real world, additional hands-on engagement, decreased challenge/complexity, increased challenge/complexity, making a game out of the lab, and working collaboratively, as well as an open-ended "other" option (Table 2). To keep surveys short and avoid priming stereotype threat (Steele & Aronson, 1995), no demographic data was collected.

Depending on the supervising instructor's preference, surveys were administered electronically (n = six courses in fall 2020 and five courses in spring 2021) or on paper (n = one course in spring 2021). Electronic forms were time-stamped for completion, and responses were removed

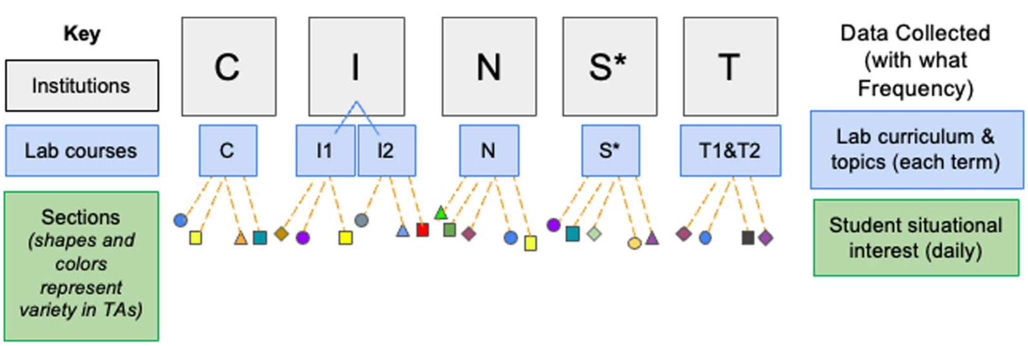

Figure 1. Specific lab categories and topics taught in Fall 2020 and Spring 2021 for which survey results were obtained from five different research universities (C, I, N, S, and T). Not all topics were covered at all universities or by all classes; a numbered letter (I1 and I2) indicates multiple courses offered at that university, and the asterisk (e.g., S*) indicates the comparison institution, where no inquiry labs designed in the EER 2020 Inquiry Workshop were included. Courses I1 and I2 are separate courses taught by different instructors at Institution I, and are treated as separate courses in the dataset; T1&T2 are two very similar courses taught by the same instructor that are therefore treated as one course from Institution T. The number of sections included in each course varied by semester, so shapes representing sections are schematic only, and do not indicate a specific number.

Table 1. Letters denote each of the five participating institutions (S*=comparison institution), and letters with a number indicate separate courses (as illustrated in Figure 1). Specific lab categories and topics included in each course, along with the courses that used each lab topic in Fall 2020 (F20) and Spring 2021 (S21). Course symbols in bold italics (e.g., ***I1*** for climate) indicate use of a lab for that topic that was created in the EER 2020 Inquiry Workshop.

Lab topic category	Lab topics included in study	F20 topics taught	S21 topics taught
Atmosphere and climate	atmospheric dynamics		T
	weather		T
	climate	***I1***, T, S*, C, I2	***I1***, I2, ***T***
	anthropogenic climate change	I2	I2
	paleoclimate (& anthropogenic for I2)	I2	I2
	ocean circulation		T
Maps	types of maps	N	N
	topographic maps	N, I2	N, C, I2
	exploration of landforms	C	C
Natural hazards	earthquakes	T, S*	C, I1, T, S*
	volcanoes and volcanic hazards	C, T, I2, I1	I1, I2, T
	landslides	I2	I2
Rocks and minerals	minerals	***C***, I1, T, S*	I1, ***T***, S*
	all rocks		***N, I2, T***
	igneous rocks	N, S*, I1	N, I1, S*
	sedimentary rocks	***N***, ***C***, T, S*, I1	***N***, S*
	metamorphic rocks	***N***, T, S*, I1	N, S*
Scientific method ("science")	introduction to scientific method	T, S*	T, S*
Solid earth	Earth's interior structure	N, T	N, T
	plate tectonics	***N***, N, ***C***, I1, I2, ***T***, T, S*	***N***, C, I1, ***I2***, S*, ***T***, T
	folds, faults, and geologic structures	I1, T	I1, T
Geologic time ("Time")	geologic time	***N***, ***I1***, S*, I2	**I1**, I2, S*
	relative dating		***N***
Virtual field trips	video or virtual globe explorations of different locations	C, I1, T	C, I1, T
Water	hydrosphere		C
	stream discharge	S*	S*
	flood frequency	S*	S*
	flooding	C	C
	groundwater	***C***, I1, ***I2***, T	***C***, I1, ***I2***, T, S*
	watersheds	I2	C, I2
	surface water	T	T
	water measurement	T	T
"Other"	deserts & wind	T	T
	soils	I2	

if they were completed more than 14 days after the corresponding lab; completion date was not recorded for paper forms, but surveys were collected contemporaneously with the labs themselves. Duplicate responses were removed, yielding 6,463 survey responses (2,535 in fall 2020 and 3,928 in spring 2021). Responses in which students answered some but not all questions were retained if any interest information was provided, with incomplete responses removed during analysis for individual survey questions. This data cleaning process resulted in different sample sizes for different questions, ranging from 6,457 for question 1 (impact of course and topic) to 1,315 for question 3 (asking students who said online labs were less interesting, "why?").

Labs were grouped into 10 topical categories defined by consensus among the three authors: atmosphere and climate, natural hazards, maps, rocks and minerals, scientific method ("science"), solid earth, geologic time ("time"), virtual field trips, water, and "other" (Table 1). We grouped virtual field

Table 2. Text of survey questions and answer choices used to ascertain students' perceptions of how interesting labs were online compared to in-person and what design features influenced students' interest in labs in the study. In this table, * indicates questions added in spring 2021.

Question	Answer choices
How interesting was this lab to you overall?	(Likert scale 1= not at all interesting to 4 = very interesting)
How interesting was the online version of this lab activity compared to what you think it would have been if you had completed the lab in person?	More interesting online Equally interesting online Less interesting online
*If you said this lab was less interesting online, which of the following reasons explain why?	Difficulty interacting with the instructor Difficulty interacting with peers Not able to physically interact with instructional materials (rocks, minerals, maps, etc.) Other (open-ended response)
*Which of the following revisions could make your interest in this lab overall go up by 1 point? (select all that apply)	Increased relevance or connection to my life experience or future career Additional opportunity to engage in authentic scientific processes (e.g., forming and testing my own hypotheses) Additional local field trip to see these geology concepts in the real world Additional hands-on engagement (handling rock samples, examining 3-D models, etc.) Decreased level of challenge/complexity Increased level of challenge/complexity Making a game out of the lab Working collaboratively in groups (if not already doing so) Other *(open-ended response)*

trip labs together for two reasons: First, virtual field trips typically explored different types of geologic features, making it impossible to categorize the lab in another topical category (e.g., water). Second, the format of the labs as a series of observations and interpretations based on the virtual globe imagery was the defining feature differentiating these labs from those in other categories.

Statistical analysis

Data were compiled and descriptive statistics analyzed using Microsoft Excel. Further analyses were conducted using IBM SPSS 28, including Kolmogorov-Smirnov tests of normality, Kruskal-Wallis tests to determine whether institutions were significantly different from one another, a two-way ANOVA to examine the effect of institution and topic on overall interest, and chi-square tests to examine associations between categorical variables. Chi-square tests reveal over- or under-selection of an answer choice (why labs were less interesting online, or what would make labs more interesting) for a given topic (e.g., rocks and minerals) compared to labs in all other topical categories.

Effect sizes for ANOVA were calculated using partial eta squared (η^2). Values between 0.01 and 0.06 are considered to represent a small effect, between 0.06 and 0.14 a medium effect, and above a 0.14 a large effect (Cohen, 2013; Fritz et al., 2012). Effect sizes for chi-square tests were calculated using phi (ϕ). ϕ values between 0.1 and 0.3 are interpreted as a small effect, 0.3 and 0.5 a medium effect, and above a 0.5 a large effect (Cohen, 2013).

Study limitations

Due to the vast scope of this study, we did not systematically analyze the lab curricula or ask instructors to report which labs or sections included synchronous online instruction or were completed asynchronously. Analysis of some features such as lab inquiry level is ongoing and will be published in the future.

During COVID, loss, illness, and fear negatively impacted students' mental health and wellness (Birmingham et al., 2023; Copeland et al., 2021; Lee et al., 2021), which may have reduced their interest in online lab activities. Positive mental contrasting (Appel et al., 2016; Verduyn et al., 2017), "Zoom fatigue" (Nesher Shoshan & Wehrt, 2022), duration of social distancing, familiarity (or lack thereof) with online learning technologies, and other contextual features likely also shaped students' interest and may not be applicable to future online lab experiences.

All five participating institutions were large research universities, so findings of similar studies may be different at other institution types (see Gilbert et al., 2012). We are unable to account for institutional, instructor, or TA influences, though instructor behaviors in online courses do impact student outcomes (e.g., d'Alessio et al., 2019). We did not ask students for demographic information, so we cannot speak to potential equity gaps in student interest that are likely due to prevailing instructional norms in STEM (Dewsbury et al., 2022; Theobald et al., 2020) and differential impacts of COVID on different groups (e.g., Hammerstein et al., 2021).

Limitations exist based on the study methodology. Likert scale questions only included text descriptors for end members (1 = not at all interesting, 4 = very interesting), so middle numbers may have been interpreted differently by participants. Though we have no reason to suspect paper surveys were regularly completed late, these were not time-stamped and therefore could not be eliminated if completed outside the two-week window applied to the electronic surveys. Asking students whether an online lab was less, equally, or more interesting than it would have been in-person asked them to imagine an experience they had not had. Answer choices to explain why a lab was less interesting online were more limited than the answer choices for what would make their interest go up, and neither set reflected all features previously found to trigger interest (e.g., narrative). As the geoscience research community further narrows the set of features that most impact interest in introductory labs, different options might be explored.

Renninger and Su (2019) indicate that observations are preferred, since learners may not be aware that their interest has been triggered at first. However, an observational approach was not feasible for a study of this size. Other researchers have approached this problem by instead asking students how much they liked an activity (Renninger & Su, 2019). Our approach is similar: We did not define "interesting" on the survey, but because triggered situational interest is primarily an affective experience, "liking" and "interesting" may be experienced similarly.

Results

Average interest ratings for online labs by topical category and course (RQ1)

Descriptive statistics showed variation in interest scores across courses and topics: Average interest scores by course ranged from 2.47 to 3.05 on a 4-point scale, with standard deviations ranging from 0.80 to 0.94 (Figure 2). Average interest scores per topic ranged from 2.55 (maps) to 2.99 (science), with standard deviations from 0.75 (science) to 0.97 (other) (Figure 3).

A two-way ANOVA showed a statistically-significant interaction between the effects of course and topic on interest, $F(20, 6395) = 4.038$, $p < .001$. Simple main effects analysis showed that topic and course each had a statistically-significant effect on interest ($p < .001$). Effect size values of η_p^2 are −0.013 for the course, 0.012 for the topic, and 0.041 for the overall model. This suggests that only about 1% of the variance in the dataset comes from either the course or topic, but taken together, these two factors explain about 4% of the variance (reflecting differences in how interesting topics are to students when taught in different courses).

Interest online vs. hypothetical in-person labs, overall and by topic (RQ2)

Out of 6,354 responses, 46.3% of students said they thought that labs were less interesting online than they thought the labs would have been in-person; 49.4% perceived them as being equally as interesting as they would have been in-person; and only 4.2% perceived online labs as more interesting than they would have been in-person (Table 3). Natural hazards labs (earthquakes, volcanoes, landslides) were most often rated as being equally interesting online compared to what students believed they would have been like in-person (60.5% of responses; Table 3). Rock and mineral labs were most often rated as less interesting online (54.8%; Table 3). Virtual field trips were most often rated as more interesting online (12.7%; Table 3).

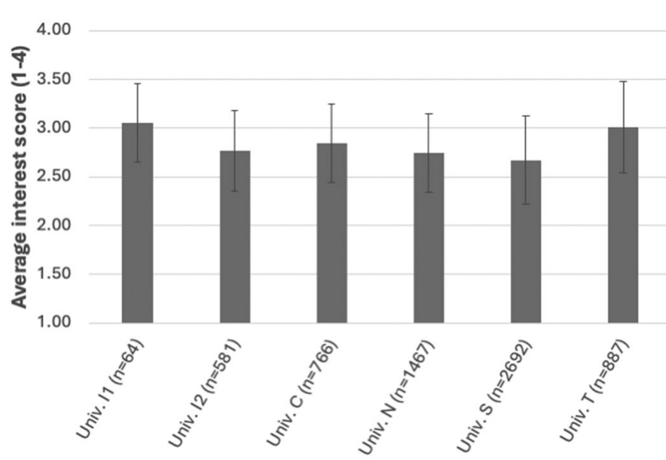

Figure 2. Average interest scores and standard deviations from course. University I includes two courses, labeled I1 and I2. Vertical error bars show standard deviation for each course.

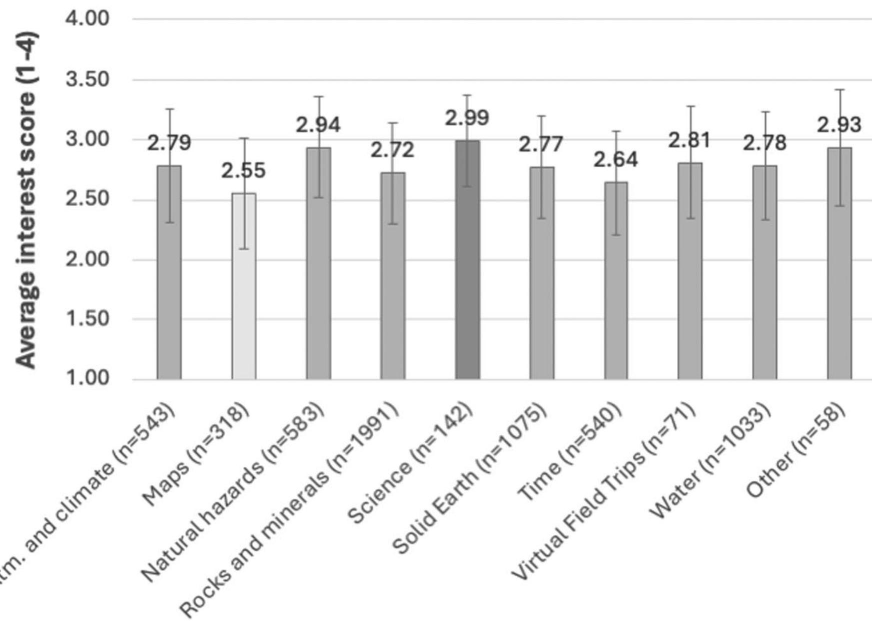

Figure 3. Average interest scores and standard deviations from each topical category. Vertical error bars show standard deviation for each topic. The highest interest score topic is shown in dark gray (science), while the lowest interest score topic is shown in light gray (maps).

Table 3. Average percentages of students' rankings for each topical category when asked: "How interesting was the online version of this lab activity compared to what you think it would have been if you had completed the lab in person?".

Topic	n	Less interesting (%)	Equally interesting (%)	More interesting (%)
All topics	6354	46.3	49.4	4.2
Atmosphere and climate	543	41.3	51.9	6.8
Maps	318	47.5	49.4	3.1
Natural hazards	583	36.0	60.5	3.4
Rocks and minerals	1991	54.8	41.8	3.4
Science	142	45.1	49.3	5.6
Solid earth	1075	44.5	51.0	4.6
Geologic time	540	41.5	54.8	3.7
Virtual field trips	71	38.0	49.3	12.7
Water	1033	42.5	53.3	4.2
Other	58	36.2	58.6	5.2

Design features influencing situational interest (RQ 3)

Why labs were less interesting online

If students reported perceiving a lab as less interesting online than it would have been in-person, they were asked to select from three possible reasons for that perception: a lack of hands-on interaction with instructional materials, difficulty interacting with peers, and difficulty interacting with the instructor (or an open-ended "other" option). 1,315 students answered the question, "If you said this lab was less interesting online, which of the following reasons explain why?" 2.8% of respondents selected "other," often in conjunction with another response (e.g., a student who selected "difficulty interacting with instructor" and "difficulty interacting with peers" wrote "non synchronous means I do it by myself"). This low percentage of "other" responses gave us confidence that our three explicit answer choices were representative, and we proceeded with analysis based on those three answer choices. Of the three specified answers, the most common answer was "Not able to physically interact with instructional materials (rocks, minerals, maps, etc.)" (56.3%; Figure 4), followed by "difficulty interacting with peers" (30.6%; Figure 4), then "difficulty interacting with the instructor" (13.2%; Figure 4). This trend holds true across all lab topic areas.

To determine whether any of these reasons were more common for particular lab topics than others, we used 2×2 chi-square tests of independence. The two comparisons made for each test were 1) whether or not a reason (e.g. difficulty interacting with peers) was selected, and 2) a single lab category vs. labs in all other categories. Results are presented in Table 4 with effect sizes (ϕ).

When compared with labs in all other categories, a lack of hands-on interaction was selected significantly more often for labs in the rocks and minerals ($p = <.001$, $\phi = .148$) and science ($p = .003$, $\phi = .077$) categories, and less often for atmosphere and climate ($p = <.001$, $\phi = -0.119$), maps ($p = .024$, $\phi = -0.065$), natural hazards ($p = .035$, $\phi = -0.058$), and solid earth labs ($p = <.001$, $\phi = -0.147$; Table 4). Difficulty interacting with peers was selected significantly more often for maps ($p = <.001$, $\phi = .096$) and solid earth labs ($p = .003$, $\phi = .082$), and less often for rocks and minerals labs ($p = <.001$, $\phi = -0.106$; Table 4). Difficulty interacting with the instructor was selected significantly more often for maps ($p = .015$, $\phi = .070$) and solid earth ($p = .003$, $\phi = .088$), and less often for rocks and mineral labs ($p = <.001$, $\phi = -0.111$; Table 4). The effect size of these relationships was small ($\phi = .1–.3$; Cohen, 2013) in four of the 12 statistically-significant relationships: under-selection of lack of hands-on interaction for atmosphere and climate and solid earth labs, over-selection of lack of hands-on interaction for rock and mineral labs, and under-selection of difficulty interacting with the instructor for rock and mineral labs (Table 4). No medium or large effect sizes were observed (Table 4).

Table 4. Results of chi-square analyses for reasons selected to explain why labs in each topic were less interesting online, related to research question 3. Virtual field trip labs were omitted from the analysis due to small sample size ($n = 4$). For all analyses, df = 1 and $n = 1315$. * denotes $p < .05$; ** denotes $p < .001$, where statistically-significant p-values indicate students were more likely to select that choice for labs in that category as compared to labs in other categories. Effect size (φ) of these relationships were small (φ = 0.1-0.3) for lack of hands-on interaction for atmosphere and climate and solid earth labs, and for all three reasons for rock and mineral labs; all others were below the lower end threshold for a small effect size (<0.1).

	Lack of hands-on interaction			Difficulty interacting with peers			Difficulty interacting with instructor		
Topic	X^2	p	ϕ	X^2	p	ϕ	X^2	p	ϕ
Atmosphere and climate	18.650	**<.001	−0.119	.236	.667	−0.013	.090	.713	.008
Maps	5.577	*.024	−0.065	12.076	**<.001	.096	6.363	*.015	.070
Natural hazards	4.465	*.035	−0.058	.017	.900	.004	1.640	.195	.035
Rocks and minerals	28.790	**<.001	.148	14.767	**<.001	−0.106	16.240	**<.001	−0.111
Science	7.800	*.003	.077	.003	1.000	.001	.151	.859	−0.011
Solid earth	28.576	**<.001	−0.147	8.793	*.003	.082	10.100	*.003	.088
Geol. time	1.381	.277	.032	1.285	.272	.031	2.353	.157	−0.042
Water	.008	1.000	.003	.238	.653	−0.013	2.326	.147	.042

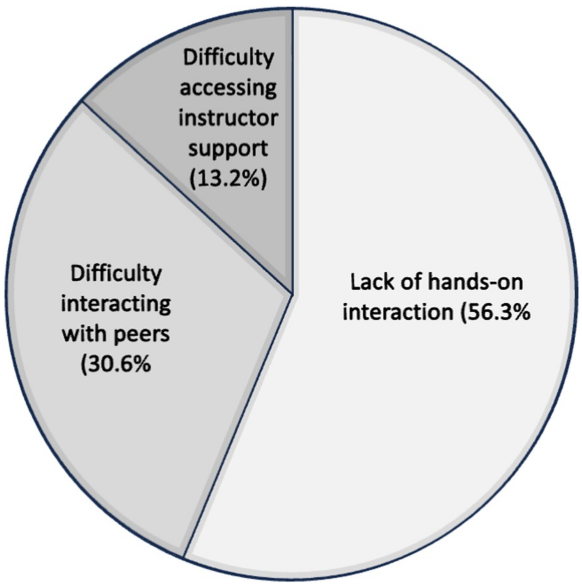

Figure 4. Percentages of each reason selected for why lab was less interesting online across all topics. Each student was limited to one answer selection for this question. This question was asked only in spring 2021.

What revisions would make labs more interesting

For the question "Which of the following revisions could make your interest in this lab overall go up by 1 point? (select all that apply)," students could select multiple answers (Table 2), resulting in 4,325 responses. The most selected revision was additional hands-on engagement (22.8%; Figure 5), followed closely by increased relevance (20.2%; Figure 5), then making a game out of the lab (16.9%), a local field trip (13.4%; Figure 5), and decreased challenge or complexity of the lab (11.8%; Figure 5).

Additional hands-on interaction and increased relevance are the top two revisions selected for most topics. Hands-on ranked first on maps, rocks and minerals, and geologic time labs, and increased relevance ranked first on atmosphere and climate, natural hazards, science, solid earth, and water labs (Table 5). A local field trip was the most-often selected option for labs in the virtual field trips category (Table 5). Increased relevance was the second-most selected option for maps, followed closely by decreased challenge (Table 5). Making a game out of the lab was the second-most-selected option for solid earth labs (Table 5). In the open-ended "other" field, 73 individual responses were provided. Many of the open-ended comments indicated a need for clearer or more detailed instructions (24 responses), more robust or effective pre-lab instruction (12 responses), and more effective collaboration (6 responses).

We used 2 × 2 chi-square tests of independence to statistically assess whether any of these reasons were more frequently selected for particular lab topics. The two comparisons made for each test parallel those described above: 1) whether or not a reason (e.g. decreased challenge) was selected, and 2) a single lab category vs. labs in all other categories. Results are presented in Table 6 with effect sizes (ϕ).

When compared with labs in all other categories, hands-on interaction was selected significantly more often for rocks and minerals labs ($p = <.001$, $\phi = .112$) and less often for solid earth ($p = .048$, $\phi = -0.039$) and water labs ($p = .001$, $\phi = -0.063$; Table 6). Increased relevance was selected more often for labs in the science category ($p = <.001$, $\phi = .0.68$; Table 6). Making the lab a game was selected significantly more often for labs in the following categories: science ($p = <.001$, $\phi = .069$), solid earth ($p = .013$, $\phi = .049$), and geologic time ($p = .019$, $\phi = .047$; Table 6). Making the lab a game was selected significantly less often for atmosphere and climate ($p = <.001$, $\phi = -0.066$) and water labs ($p = <.001$, $\phi = -0.69$; Table 6). Providing a local field trip was selected significantly more often for science ($p = .021$, $\phi = .046$) and water labs ($p = <.001$, $\phi = .066$) and significantly less often for rock and mineral labs ($p = .021$, $\phi = -0.046$; Table 6). Decreasing the challenge level was selected more often for maps ($p = <.001$, $\phi = .105$) and solid earth labs ($p = .008$, $\phi = .053$), and less often for rocks and mineral labs ($p = <.001$, $\phi = -0.083$; Table 6). Inquiry was selected more often for labs in the science category ($p = .042$, $\phi = .041$; Table 6). Collaboration was selected significantly more often for maps ($p = <.001$, $\phi = .083$) and science ($p = .032$, $\phi = .043$) labs and less often for rocks and minerals labs ($p = .013$, $\phi = -0.049$; Table 6). Finally, increased challenge was selected more often for labs in the science category ($p = .021$, $\phi = .046$; Table 6). There was a small effect size ($\phi = .1–.3$; Cohen, 2013) for the positive association between hands-on interaction and rocks and minerals labs, and decreased challenge for labs in the maps category (Table 6). All other effect sizes fell below the threshold for small effects (< 0.1; Cohen, 2013; Table 6).

Table 5. Percentage of each option selected for what revision would make the lab more interesting, by topical category (no responses were provided for labs in the "other" category), related to research question 3.

Topic	n	Hands-on (%)	Relevance (%)	Game (%)	Field trip (%)	Decreased challenge (%)	More inquiry (%)	Collaboration (%)	Increased challenge (%)
Atmosphere and climate	178	19.7	22.5	11.2	12.4	14.0	10.1	8.4	1.7
Maps	406	18.7	17.2	15.8	14.3	17.0	5.4	9.6	2.0
Natural hazards	275	20.4	20.7	17.8	14.6	10.2	6.2	7.3	2.9
Rocks and minerals	1476	28.0	19.7	16.8	12.3	9.4	6.4	5.2	2.2
Science	256	19.5	21.9	19.1	14.1	7.0	7.4	7.4	3.5
Solid earth	503	19.3	21.3	20.1	10.5	14.9	7.6	4.6	1.8
Geologic time	491	23.6	21.4	20.8	11.4	11.0	5.7	4.5	1.6
Virtual field trips	9	22.2	0	0	77.8	0	0	0	0
Water	731	19.3	20.4	13.1	17.4	13.8	5.5	7.7	2.9

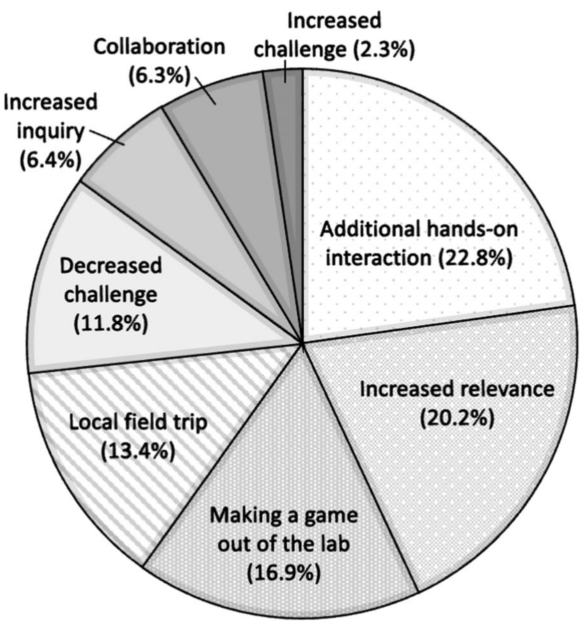

Figure 5. Percentages of each option selected for what revisions would make a lab more interesting (all topics). Each student was allowed to select as many answer options as they wanted to for this question. This question was asked only in spring 2021.

Discussion

Triggered situational interest is a primarily affective response to something in the environment (Hidi & Renninger; 2006; Renninger & Hidi, 2016). Viewed within this framework, online lab activities may trigger interest, enhancing motivation and learning as a result. Below we discuss which online lab activity design features students report as influencing their interest in light of prior research.

Interest for online labs by topical category and course (RQ1)

The topical category of a lab and the course in which students are enrolled each explains about 1% of the variance in student interest scores. The interaction between them explains only about 4% of the variance in interest scores, leaving 96% of the variance to other factors, or combinations of factors. Such factors may include the design features listed as answer choices for the second and third questions in Table 2, highly-individualized factors like previously-developed student individual interest (Hidi & Renninger, 2006; Renninger & Hidi, 2016; Renninger & Su, 2019), and relatively consistent factors like the fact that students in the U.S. are often required to take at least one lab science course to meet general education requirements (e.g., Warner & Koeppel, 2009).

Topical category

Consistent with prior work suggesting that interest may be triggered by specific topics (Bergin, 1999; Pelch & McConnell, 2017; Schank, 1979; Teasdale et al., 2018a; Trend, 2005; Wade et al., 1993), the topical category in our dataset has a small but significant impact on student interest. Average student interest scores were highest for labs in the science and natural hazards categories, and lowest for labs in the maps and geologic time categories (Figure 3).

Labs in the science category in our dataset came at the beginning of the semester, and we infer that they may have served to introduce students to the scientific method by walking students step-by-step through the inquiry process. Therefore, high interest ratings for these labs (Figure 3) are consistent with prior work indicating that well-scaffolded inquiry can trigger interest, especially for novices (Maltese & Harsh, 2015; Palmer, 2009; Plenge et al., 2022; van der Hoeven Kraft, 2017). Student choice and autonomy are both defining features of higher levels of inquiry (Buck et al., 2008) and linked to interest (Alexander et al., 1997; Renninger et al., 2015; Renninger & Su, 2019; van der Hoeven Kraft, 2017). To fully leverage the potential for inquiry to enhance interest, instructors might use inquiry in labs later in the semester as well, or increase the level of inquiry as the semester progresses (e.g., Wildan et al., 2019).

High interest ratings on natural hazards labs (Figure 3) align with prior findings that danger or otherwise emotionally charged topics may be inherently interesting (Schank, 1979; Wade et al., 1993). Since hazards like earthquakes and landslides directly impact society, high interest ratings may also be partly explained by prior findings that socioscientific issues interest students (Pelch & McConnell, 2017; Teasdale et al., 2018a). Not all courses in our study included labs on natural hazards (Table 1). Including natural hazard labs that highlight the societal relevance of those phenomena may help to trigger student interest in introductory geology lab curricula.

Maps and geologic time categories received the lowest interest ratings in the study. A deeper assessment of the

Table 6. Results of chi square analyses for revisions that would increase students' interest in labs in each topic, related to research question 3. Virtual field trip labs were omitted from the analysis due to small sample size ($n=8$). For all analyses, df = 1 and $n=2527$. * denotes $p<.05$; ** denotes $p<.001$. There was a small effect size ($\varphi=0.1$-0.3) for the difference in selecting hands-on interaction as a revision that would make rocks and minerals labs more interesting, and decreased challenge as a revision that would make maps labs more interesting; all others were below the lower end threshold for a small effect size (<0.1).

	Hands-on interaction			Increased relevance			Making the lab a game			Local field trip		
Topic	X^2	p	ϕ	X^2	p	ϕ	X^2	p	ϕ	X^2	p	ϕ
Atmosphere and climate	7.042	*.009	−.053	.486	.503	−.014	10.877	**<.001	−.066	2.26	.157	−.030
Maps	.095	.821	−.006	.013	.938	.002	1.051	.329	.020	4.492	*.043	.042
Natural hazards	3.030	.088	−.035	.135	.740	−.007	.003	1.000	−.001	.020	.925	.003
Rocks and minerals	31.498	**<.001	.112	2.259	.133	−.030	.647	.421	−.016	5.313	*.021	−.046
Science	1.359	.244	.023	11.651	**<.001	.068	12.141	**<.001	.069	5.306	*.021	.046
Solid earth	3.893	*.048	−.039	.917	.338	.019	6.129	*.013	.049	3.804	.051	−.039
Geol. Time	.027	.870	.003	.174	.677	.008	5.538	*.019	.047	2.868	.090	−.034
Water	10.127	*.001	−.063	.066	.798	−.005	12.186	**<.001	−.069	11.153	**<.001	.066

	Decreased Challenge			Inquiry			Collaboration			Increased challenge		
Topic	X^2	p	ϕ	X^2	p	ϕ	X^2	p	ϕ	X^2	p	ϕ
Atmosphere and climate	.007	1.00	−.002	1.501	.240	.024	.193	.657	.009	.797	.483	−.018
Maps	27.834	**<.001	.105	.000	1.000	.000	17.471	**<.001	.083	.009	.849	.002
Natural hazards	1.619	.236	−.025	.196	.800	−.009	.181	.700	.008	.315	.537	.011
Rocks and minerals	17.485	**<.001	−.083	.116	.733	−.007	6.164	*.013	−.049	.294	.587	−.011
Science	1.305	.253	−.023	4.151	*.042	.041	4.582	*.032	.043	5.299	*.021	.046
Solid earth	7.032	*.008	.053	1.660	.198	.026	2.545	.111	−.032	.495	.482	−.014
Geol. Time	.652	.419	−.016	.705	.401	−.017	3.651	.056	−.038	1.195	.274	−.022
Water	2.897	.089	.034	1.770	.183	−.026	2.412	.120	.031	1.219	.270	.022

curriculum of labs in these categories may be necessary to determine why. However, problem-solving in both areas requires students to remember, understand, and apply multiple rules or principles (rule of v's, contour intervals; principle of superposition, cross-cutting relationships, etc.), resulting in substantial use of working memory and high cognitive load (Sweller, 1988). Visualizing a three-dimensional landscape from a two-dimensional map also requires spatial thinking skills that may not be well developed for many introductory geology students (Liben & Titus, 2012; Rapp et al., 2007). Visualizing the development of geologic structures over time similarly requires spatial and temporal reasoning skills with which novices may struggle (Dodick & Orion, 2003; Kali & Orion, 1996). High cognitive load may also result when students must first conceptualize deep time, then read and understand scientific notation or large numbers, and finally apply that knowledge to answer a question (Cheek, 2012; Cheek et al., 2017).

When cognitive load is high, students may want more support (ranging from explicit instruction or peer collaboration to animations, resources, or hints built into the learning management system). Previous work has shown that interest may wane if students perceive that they do not have sufficient support for a task given their existing skills and knowledge (Bergin, 1999; Renninger & Hidi, 2016; Renninger & Lipstein, 2006; Renninger & Su, 2019). High cognitive load, coupled with contextual factors making support feel less accessible online than in-person, may explain the low ratings for maps and geologic time topics. Therefore, to maintain student interest in online labs on these topics, it may be especially important to reduce cognitive load. To do so, activities should provide clear instructions and ample practice applying a single rule or principle at a time before asking students to integrate them (Allan et al., 2019). Student interest may also benefit disproportionately from synchronous learning sessions with breakout groups or automated hints embedded within the lab or learning management system.

Course

Similar to topic, the course students were enrolled in has a small but statistically-significant impact on average interest ratings in our dataset. Course attributes (Donham et al., 2022b) include features for which we did not collect systematic data in this study, such as the amount of TA training and experience, pedagogical practices (Huffmyer & Lemus, 2019), TA behaviors to create a positive learning environment (O'Neal et al., 2007) or encourage help-seeking or interaction with other students, whether and how technology was used (e.g., small group breakout room sessions, availability and duration of synchronous lab meetings), and student and TA familiarity with the technology used (Donham et al., 2022a; Lark et al., 2020). All of these features and many others are subsumed by our course variable.

Interest online vs. hypothetical in-person labs (RQ2)

On our weekly surveys, we asked students how interesting the online version of the lab was compared to a hypothetical in-person version (wording in Table 2). Here, we discuss results for the overall dataset, followed by a breakdown by topic.

Overall interest in online vs. hypothetical labs

Most students thought labs were equally as interesting online as they would be in person, and a few thought labs were more interesting online (Table 3). These numbers are consistent with pre-pandemic literature indicating a significant student demand for online courses, which has been attributed to the greater flexibility online courses offer in terms of where and (with asynchronous models) when students complete coursework (Allen & Seaman, 2010; Beldarrain, 2006).

However, nearly half of students said that labs were less interesting online than they would have been in-person (Table 3). The fact that students are nearly equally divided on whether labs were equally or less interesting online may suggest value in offering students a choice regarding course format, which may also encourage interest development (Alexander et al., 1997; Renninger et al., 2015; van der Hoeven Kraft, 2017). COVID conditions during this study meant that many students were forced to take labs online, which may have prompted mental contrasting in which they imagined an in-person lab might have been better (Appel et al., 2016; Verduyn et al., 2017). During COVID, students also experienced isolation and negative impacts on their mental health (Copeland et al., 2021; Wang et al., 2020). Therefore, the percentage of students in this study who said that labs were less interesting online may be larger than it would have been without those additional stressors.

Interest in online vs. hypothetical labs for different topical categories

To understand how topical category influenced student interest, we discuss topics with the greatest number of responses indicating that labs were more, equally, and less interesting online (Table 2).

Labs in the natural hazards topical category had the greatest percentage of students who selected "equally interesting online" (60.5%; Table 3). As noted in the discussion of research question one, the societal relevance and emotional draw of danger related to natural hazards may hold inherent interest for students (Pelch & McConnell, 2017; Schank, 1979; Teasdale et al., 2018b; Wade et al., 1993), allowing these labs to translate relatively well across contexts.

Labs in the virtual field trips category were most frequently cited as being more interesting online (12.7%; Table 3). Virtual field trips are increasingly used in the geosciences (e.g., Çaliskan, 2011; Dolphin et al., 2019; Hurst, 1998), and have been associated with enhanced conceptual learning and content knowledge (Bitting et al., 2018; Mead et al., 2019) as well as interest (Bursztyn et al., 2017). The varied colors and textures of virtual globe imagery may trigger interest by appealing to students' sense of aesthetics (Lin et al., 2013; Trend, 2005). The ability to visit multiple, sometimes far-away, locations, navigate around the world, and explore geologic features at different scales may also result in an experience of novelty, another documented interest trigger (Lin et al., 2013). Only half the courses in our study included virtual field trips (Table 1). Especially for online labs, taking advantage of virtual field trips created by the geoscience community (for example, see Lenkeit Meezan & Cuffey, 2012; Teach the Earth, n.d.) may help spark students' interest.

Labs in the rock and minerals category received the highest percentage of "less interesting online" responses (54.8%; Table 3). While we have not systematically analyzed the curriculum of labs in our dataset, online rock and mineral labs often follow a traditional classification model using photos or videos of rocks and minerals accompanied by hypothetical test results (Piper et al., 2024), as did the online mineral lab created during the Earth Educators' Rendezvous (Teasdale et al., 2021a) that was used by two institutions in the study (Table 1). This format eliminates any hands-on experience that might enhance interest (Bergin, 1999). Online labs that incorporate rock and mineral identification may find student interest is higher if students can use kits of hand samples and testing materials, potentially alongside support such as a synchronous virtual class meeting.

Design features influencing situational interest (RQ3)

The two questions on the survey that speak to the design features students believe influenced their situational interest are displayed in Table 2. First, we address overall results for the two questions. We then address results by topic, focused on findings that are both statistically-significant and reach the threshold for a small effect size.

Why labs were less interesting online, and what would make them more interesting

Inability to physically interact with materials was by far the most commonly cited reason why labs were less interesting online (56.3%; Figure 4) and was also the most commonly recommended revision to make labs more interesting (22.8%, Figure 5). This result is consistent with prior literature suggesting that hands-on experiences may trigger situational interest (Bergin, 1999; Grissom, 2014). Online lab designers might explore a variety of ways to incorporate hands-on activities, from rock and mineral kits to using common household items to illustrate geological phenomena (e.g., modeling rock deformation with spaghetti, LaDue & Schwartz, n.d.).

Between the two other answer choices offered for what made labs less interesting online, students selected difficulty interacting with peers more than twice as often as they selected difficulty accessing instructor support (30.6% vs. 13.2% of responses, respectively; Figure 4). Many competing explanations might explain these results. For example, the desire for peer interaction might reflect the isolation students experienced during COVID (Donham et al., 2022a; Leal Filho et al., 2021), their perception that collaboration is interesting in general (Yuretich et al., 2001), that students generally prefer to ask a peer for help rather than asking an instructor (Qayyum, 2018), or some combination thereof. Alternatively, this pattern of responses might indicate that students were relatively comfortable contacting their TAs for help (as reported by Kitsantas & Chow, 2007) and therefore did not feel this type of support was lacking. Future interviews or focus groups might explore these or other potential explanations.

Of the answer choices offered for what would make labs more interesting, students' frequent overall selection of additional hands-on engagement, relevance, and making a game of the lab (Figure 5, 22.8%, 20.2%, 16.9%, respectively) aligns well with Grissom's (2014) findings regarding how students explained why in-person lab activities were interesting. This consistency suggests that similar design features may drive interest in both online and in-person contexts, though future work should test this hypothesis directly.

Though it did not stand out in statistical comparisons (Table 6), additional relevance to students' life experience or future career was the most-frequently chosen revision for atmosphere and climate, natural hazards, solid earth, science, and water labs (Table 5), and the second-most-frequently selected revision overall (Figure 5). As instructors, we view many of these topics (e.g., climate, hazards, water) as inherently relevant to living in the twenty-first century, but student responses suggest that more explicit connections need to be made with students lived experiences, and how potential future impacts could affect them directly. Existing models using this approach include the InTeGrate project materials (Gosselin et al., 2019; Teasdale et al., 2018b), materials using real-time data to engage students in hazard monitoring (Teasdale et al., 2015), citizen science projects (Jenkins, 2011), place-based courses and activities (Gosselin et al., 2016; Semken et al., 2017), and other local project-based learning models (e.g., Eick et al., 2008; St. John & Callahan, 2003).

Making a game out of the lab represented more than 20% of the selections for how to make labs in the solid earth and geologic time labs more interesting (Table 5) and was also selected more frequently for labs in the atmosphere and climate, science, and water categories (Table 6). Game-based learning has expanded rapidly in recent decades (Brown et al., 2018; Maraffi et al., 2017), and has been directly linked to increased interest, engagement, motivation, and enthusiasm, as well as reduced learning anxiety (Chen et al., 2021; Gates & Kalczynski, 2016; Robertson, 2022). Game-based learning has also been associated with enhanced overall learning in science and improvements in problem solving, collaboration, and critical thinking (Chen et al., 2021; Lei et al., 2022). From cookie-mining for "ore" (Grissom, 2014) and competitions around what to do during an earthquake (Musacchio et al., 2015) to "Taphonomy: Dead and Fossilized" (Martindale & Weiss, 2020), many geoscience-specific examples of game-based learning are available for adoption or adaptation. Future research might further explore the geoscience topics for which game-based learning is most effective at generating interest.

The fourth-most-selected feature (Figure 5) was an "additional local field trip to see these geology concepts in the real world." Students might imagine that field trips would allow them to interact with geologic features, triggering interest *via* hands-on experiences or novelty. Especially during COVID, they may also believe field trips provide opportunities to interact with peers who might support their learning and enjoyment thereof. This result aligns with prior findings indicating that field experiences trigger and develop interest for geoscience majors (Hoyer & Hastie, 2022; LaDue & Pacheco, 2013). Although we do not know how many participants were geology majors, introductory geoscience courses like those in our study frequently enroll many non-majors (Gilbert et al., 2012). Therefore, future work might investigate whether and how field trips help to increase geoscience interest for non-majors.

Situational interest in online vs. hypothetical labs for different topical categories

Statistical analyses of students' selections for what made labs less interesting online and what would make them more interesting, according to topic, are shown in Tables 4 and 6. Table 5 shows students' recommended revisions for each topic as a percentage of responses, providing additional insights for categories in which no statistically-significant results were found. Instructors might leverage the results displayed in these three tables to guide lab revisions to enhance student interest in each category.

For example, students ranked labs in the science topical category as most interesting (Figure 3), but the lack of hands-on engagement was most often selected to explain why these labs were less interesting online (compared to labs in other topical categories; Table 4). Additional hands-on interaction was selected for what would improve student interest in labs in the science category (Table 6). The next most common student selections for this category suggest increasing relevance and making a game out of the lab (Table 5). Therefore, an instructor might combine several of these design elements to create even more interesting labs in the science category.

Relatively few chi-square analyses had effect sizes that reached the threshold for even a small effect (ϕ=.1-.3; Cohen, 2013). This indicates that the reasons students chose to explain why labs are less interesting and the revisions they selected to make labs more interesting rarely differ substantially across topics, even when those differences are statistically-significant. Below, we address the few topical categories for which small effect sizes were found and discuss them in light of other statistically-significant results for that category and prior literature that might help explain these findings.

Rocks and minerals. Students selected a lack of interaction with instructional materials more often for rock and mineral labs to explain why they were less interesting online (Table 4) and selected additional hands-on interaction more often to explain what would make them more interesting (both had small effect sizes). Perhaps as a result of students' strong emphasis on hands-on learning, they selected several other answer choices on both questions significantly less often than for labs in other categories.

As described in the discussion for research question 1 above, online rock and mineral labs frequently rely on photos or videos of samples accompanied by values students would traditionally have determined by direct testing of the sample. For mineral labs, perhaps remembering the results of acid and scratch tests they did not complete themselves increased the cognitive load for students compared to direct multisensory (hands-on) experiences with those tests that would have better encoded the features of a sample in students' working memories (Quak et al., 2015). Incorporating rock and mineral sample kits may therefore increase interest by hands-on engagement alone (Bergin, 1999; Grissom, 2014) as noted above, and also reduce cognitive load to better support students' learning and interest development

(Renninger & Hidi, 2019; Renninger & Lipstein, 2006; Renninger & Su, 2019).

Although we infer that cognitive load issues likely impacted student interest in rock and mineral labs, few responses indicated that a decreased level of challenge would increase students' interest (9.4%; Table 5). This discrepancy might be explained by a lack of metacognitive awareness: Just as learners may not be aware that their interest has been triggered at first (Renninger & Su, 2019), it is possible that novices may not be clear on what they need to do and therefore unaware that the degree of difficulty of a task is too high (as described by Sprague & Stuart, 2000 and illustrated on p. 97 of Ambrose et al., 2010). Future interview studies or "think-alouds" with novice geoscience learners might investigate this hypothesis.

Maps. For labs in the maps category, a high degree of difficulty and corresponding need for more learning support is consistent across student responses. For what made the lab less interesting online, students selected difficulty interacting with peers and difficulty interacting with the instructor more often than for labs in other categories (Table 4). For what would make the labs more interesting, they more often selected a decreased level of challenge (with a small effect size) and working collaboratively in groups (Table 6). The high level of challenge and need for additional support may help to explain why labs in the maps category had some of the lowest interest scores overall (Figure 3).

As described under research question 1, visualizing three-dimensional landforms requires spatial thinking abilities that introductory students may not yet have mastered (Liben & Titus, 2012; Rapp et al., 2007), while integrating multiple rules or principles may result in a high level of cognitive load (Sweller, 1988). Recommendations described under research question 1 therefore also apply here: scaffold map interpretation (Allan et al., 2019), automate guidance in the learning management system, and ensure that students can access instructor or peer help easily. As discussed for rock and mineral labs, these additional learning supports are likely to increase interest (Renninger & Hidi, 2019; Renninger & Lipstein, 2006; Renninger & Su, 2019) and enhance learning overall.

Solid earth. Similar to labs in the maps category, difficulty and adequate support seem to be the primary factors underlying statistically-significant results in the solid earth category. To explain why labs in the solid earth category were less interesting online, students selected a lack of physical interaction with instructional materials less often than for other categories (small effect size), but this may be primarily because they selected difficulty interacting with peers and difficulty interacting with the instructor more often (Table 4). For what would make solid earth labs more interesting, students selected a decreased level of challenge and making a game out of the lab (Table 6).

The solid earth category includes plate tectonics and crustal deformation, which in face-to-face labs frequently leverage physical models of structures and processes (e.g., Bair, 2019; earthScope ANGLE, n.d.; Kastens & Ishikawa, n.d.) that students manipulate and rotate to understand the processes at play over time and in three dimensions. However, students rarely selected "inability to physically interact with materials" to explain what made solid earth labs less interesting online (Table 4). We hypothesize that intro students who have not interacted with such models before, may not have been able to envision physical materials that would support their learning of these topics.

However, students' lived experience of these labs being too difficult and their desire for additional support from peers and the instructor may still be, in part, a function of the lack of hands-on materials. Physical models may help to alleviate the cognitive load and level of difficulty introductory students experience with spatial thinking and visualization processes (Kali & Orion, 1996; Liben & Titus, 2012). Therefore, providing physical models, scaffolding student practice of skills one at a time, offering synchronous classes, and incorporating additional learning supports such as animations (Cohen & Hegarty, 2014; Mills et al., 2020) are revisions that are likely to enhance interest in solid earth labs online.

Students' statistically-significant over-selection of "making a game out of the labs" for solid earth labs is a finding we struggle to explain, though we acknowledge that the effect size of this finding is below the "small" threshold. Perhaps when experiencing a high degree of difficulty, they imagined that fun would increase their interest. Future work should better examine this possibility.

Conclusions

In instructional settings like online labs, situational interest plays a key role in student engagement and motivation (Hidi & Renninger, 2006; Renninger & Su, 2019; van der Hoeven Kraft, 2017). Therefore, investigating student self-reports of the experience of interest and what triggers or undermines it can allow us to tailor our courses and instructional activities to better foster this outcome. What triggers interest for any given individual is highly personal, but a few predominant approaches to enhancing online labs come from the results of this study:

- Ensure that students in online labs have access to low-cost hands-on learning materials, such as rock and mineral testing kits and structural models for visualizing three-dimensional structures and processes (perhaps via a library loan program or open classroom with these materials that students can visit).
- Emphasize the explicit relevance of course content to society, and to students' lived realities or career goals, in more explicit ways and with greater frequency.
- Explore the potential to incorporate game-based activities and supplement the online lab curriculum with local in-person field trips, if logistics allow.

Note that for a few topics (science, solid earth, and maps), students often selected multiple design features that would have increased their interest more often than for other topics, so combinations of the design features listed here may be appropriate. In addition, based on our analysis of student response patterns related to the types of tasks and content students were working on, it may be helpful to modify labs to reduce the cognitive load and increase the level of peer, instructor, or other support for learning difficult topics—especially those that ask students to visualize two-dimensional representations in three dimensions (e.g., maps, structures).

These findings are likely applicable to online labs generally, though the degree to which student interest was impacted by the unique conditions of COVID should be further explored. Additional work directly analyzing the curriculum of online labs relative to student-reported design features would provide a more comprehensive understanding of situational interest triggers. Finally, future geoscience education research should draw upon these findings and explore their applicability to the design of in-person labs as well: Are students inherently more interested in science and natural hazards labs, as compared to those on maps and time, overall or just in online contexts? Do increased hands-on interaction, greater relevance, and game-based labs increase students' situational interest equally across instructional contexts? Future work is necessary to address these important questions, allowing the geoscience community to better foster student interest in our field.

Acknowledgements

The authors are grateful for the efforts of the instructors and teaching assistants at the five participating institutions who helped to collect the data, as well as the students who provided it. This manuscript benefited from the insights of four anonymous reviewers, as well as the Associate Editor and Editor who shepherded it through the review process and added additional feedback and guidance for revision. This material is based upon work supported by the National Science Foundation under Grant Numbers 1933488 and 1933395.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This material is based upon work supported by the National Science Foundation Improving Undergraduate STEM Education Program under Grants No. DUE-1933395 and DUE-1933488. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

ORCID

Kelsey S. Bitting http://orcid.org/0000-0003-3380-3822
Katherine Ryker http://orcid.org/0000-0002-3781-3422
Rachel Teasdale http://orcid.org/0000-0003-1820-8312

References

Alexander, P. A., Murphy, P. K., Woods, B. S., Duhon, K. E., & Parker, D. (1997). College instruction and concomitant changes in students' knowledge, interest, and strategy use: A study of domain learning. *Contemporary Educational Psychology*, *22*(2), 125–146. https://doi.org/10.1006/ceps.1997.0927

Allan, C. N., Crough, J., Green, D., & Brent, G. (2019). Designing rich, evidence-based learning experiences in STEM higher education. In Blended *learning designs* in STEM *higher education*: Putting *learning first* (pp. 339–363). Springer.

Allen, I. E., & Seaman, J. (2010). *Learning on demand: Online education in the United States, 2009*. Sloan Consortium.

Ambrose, S. A., Bridges, M. W., DiPietro, M., Lovett, M. C., & Norman, M. K. (2010). *How learning works: Seven research-based principles for smart teaching*. John Wiley & Sons.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). American Psychiatric Association. https://doi.org/10.1176/appi.books.9780890425596

Appel, H., Gerlach, A. L., & Crusius, J. (2016). The interplay between Facebook use, social comparison, envy, and depression. *Current Opinion in Psychology*, *9*, 44–49. https://doi.org/10.1016/j.copsyc.2015.10.006

Ayega, D., & Khan, A. (2020). Students experience on the efficacy of virtual labs in online biology. In 2020 The 4th International Conference on *education and e*-learning (pp. 75–79). https://doi.org/10.1145/3439147.3439170

Badaru, K. A., Adu, K. O., Adu, E. O., & Duku, N. (2022). Teaching in a pandemic: An exploratory study into university instructors' perceptions of work-from-home opportunities and challenges during the COVID-19 lockdown in South Africa. *International Journal of Learning, Teaching and Educational Research*, *21*(7), 286–304. https://doi.org/10.26803/ijlter.21.7.15

Bair, A. (2019). *Teaching about geologic structures with craft foam models and hands-on guided exploration activities*. Earth Educators Rendezvous. https://serc.carleton.edu/earth_rendezvous/2019/program/demos/fridayA/218476.html.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. Freeman.

Beldarrain, Y. (2006). Distance education trends: Integrating new technologies to foster student interaction and collaboration. *Distance Education*, *27*(2), 139–153. https://doi.org/10.1080/01587910600789498

Bergin, D. A. (1999). Influences on classroom interest. *Educational Psychologist*, *34*(2), 87–98. https://doi.org/10.1207/s15326985ep3402_2

Bertsch, C., Kapelari, S., & Unterbruner, U. (2014). From cookbook experiments to inquiry based primary science: Influence of inquiry based lessons on interest and conceptual understanding. *Inquiry in Primary Science Education*, *1*, 20–31.

Birmingham, W. C., Wadsworth, L. L., Lassetter, J. H., Graff, T. C., Lauren, E., & Hung, M. (2023). COVID-19 lockdown: Impact on college students' lives. *Journal of American College Health: J of ACH*, *71*(3), 879–893. https://doi.org/10.1080/07448481.2021.1909041

Bitting, K. S., McCartney, M. J., Denning, K. R., & Roberts, J. A. (2018). Conceptual learning outcomes of virtual experiential learning: Results of google earth exploration in introductory geoscience courses. *Research in Science Education*, *48*(3), 533–548. https://doi.org/10.1007/s11165-016-9577-z

Brown, C. L., Comunale, M. A., Wigdahl, B., & Urdaneta-Hartmann, S. (2018). Current climate for digital game-based learning of science in further and higher education. *FEMS Microbiology Letters*, *365*(21), fny237. https://doi.org/10.1093/femsle/fny237

Buck, L. B., Bretz, S. L., & Towns, M. H. (2008). Characterizing the level of inquiry in the undergraduate laboratory. *Journal of College Science Teaching*, *38*(1), 52–58.

Bursztyn, N., Shelton, B., Walker, A., & Pederson, J. (2017). Increasing undergraduate interest to learn geoscience with GPS-based augmented reality field trips on students' own smartphones. *GSA Today*, *27*(5), 4–10. https://doi.org/10.1130/GSATG304A.1

Çaliskan, O. (2011). Virtual field trips in education of earth and environmental sciences. *Procedia-Social and Behavioral Sciences*, *15*, 3239–3243.

Cheek, K. A. (2012). Students' understanding of large numbers as a key factor in their understanding of geologic time. *International Journal of Science and Mathematics Education*, *10*(5), 1047–1069. https://doi.org/10.1007/s10763-011-9312-1

Cheek, K. A., LaDue, N. D., & Shipley, T. F. (2017). Learning about spatial and temporal scale: Current research, psychological processes, and classroom implications. *Journal of Geoscience Education*, *65*(4), 455–472. https://doi.org/10.5408/16-213.1

Chen, P. Y., Hwang, G. J., Yeh, S. Y., Chen, Y. T., Chen, T. W., & Chien, C. H. (2021). Three decades of game-based learning in science and mathematics education: An integrated bibliometric analysis and systematic review. *Journal of Computers in Education*, *9*(3), 455–476. https://doi.org/10.1007/s40692-021-00210-y

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. Routledge.

Cohen, C. A., & Hegarty, M. (2014). Visualizing cross sections: Training spatial thinking using interactive animations and virtual objects. *Learning and Individual Differences*, *33*, 63–71. https://doi.org/10.1016/j.lindif.2014.04.002

Colthorpe, K., & Ainscough, L. (2021). Do-it-yourself physiology labs: Can hands-on laboratory classes be effectively replicated online? *Advances in Physiology Education*, *45*(1), 95–102. https://doi.org/10.1152/advan.00205.2020

Copeland, W. E., McGinnis, E., Bai, Y., Adams, Z., Nardone, H., Devadanam, V., Rettew, J., & Hudziak, J. J. (2021). Impact of COVID-19 pandemic on college student mental health and wellness. *Journal of the American Academy of Child and Adolescent Psychiatry*, *60*(1), 134–141.e2. https://doi.org/10.1016/j.jaac.2020.08.466

Crouch, C. H., Wisittanawat, P., Cai, M., & Renninger, K. A. (2018). Life science students' attitudes, interest, and performance in introductory physics for life sciences: An exploratory study. *Physical Review Physics Education Research*, *14*(1), 010111. https://doi.org/10.1103/PhysRevPhysEducRes.14.010111

d'Alessio, M. A., Lundquist, L. L., Schwartz, J. J., Pedone, V., Pavia, J., & Fleck, J. (2019). Social presence enhances student performance in an online geology course but depends on instructor facilitation. *Journal of Geoscience Education*, *67*(3), 222–236. https://doi.org/10.1080/10899995.2019.1580179

Davies, R. M., Wolk-Stanley, J., Yuan, V., & Contino, J. (2023). Building science knowledge, identity, and interest using place-based learning with non-dominant urban undergraduate and high school students. *Journal of Geoscience Education*, 1–11. https://doi.org/10.1080/10899995.2023.2186762

Dewsbury, B. M., Swanson, H. J., Moseman-Valtierra, S., & Caulkins, J. (2022). Inclusive and active pedagogies reduce academic outcome gaps and improve long-term performance. *PloS One*, *17*(6), e0268620. https://doi.org/10.1371/journal.pone.0268620

Dodick, J., & Orion, N. (2003). Cognitive factors affecting student understanding of geologic time. *Journal of Research in Science Teaching*, *40*(4), 415–442. https://doi.org/10.1002/tea.10083

Dolphin, G., Dutchak, A., Karchewski, B., & Cooper, J. (2019). Virtual field experiences in introductory geology: Addressing a capacity problem, but finding a pedagogical one. *Journal of Geoscience Education*, *67*(2), 114–130. https://doi.org/10.1080/10899995.2018.1547034

Donham, C., Barron, H. A., Alkhouri, J. S., Changaran Kumarath, M., Alejandro, W., Menke, E., & Kranzfelder, P. (2022). I will teach you here or there, I will try to teach you anywhere: Perceived supports and barriers for emergency remote teaching during the COVID-19 pandemic. *International Journal of STEM Education*, *9*(1), 25. https://doi.org/10.1186/s40594-022-00341-3

Donham, C., Pohan, C., Menke, E., & Kranzfelder, P. (2022). Increasing student engagement through course attributes, community, and classroom technology: Lessons from the pandemic. *Journal of Microbiology & Biology Education*, *23*(1), e00268-21. https://doi.org/10.1128/jmbe.00268-21

Durik, A. M., & Harackiewicz, J. M. (2007). Different strokes for different folks: How individual interest moderates the effects of situational factors on task interest. *Journal of Educational Psychology*, *99*(3), 597–610. https://doi.org/10.1037/0022-0663.99.3.597

earthScope ANGLE. (n.d.). Fault models for teaching about plate tectonics. Teach the Earth. https://serc.carleton.edu/ANGLE/educational_materials/activities/205287.html

Eick, C., Deutsch, B., Fuller, J., & Scott, F. (2008). Making science relevant. *The Science Teacher*, *75*(4), 40–45.

Faulconer, E. K., & Gruss, A. B. (2018). A review to weigh the pros and cons of online, remote, and distance science laboratory experiences. *International Review of Research in Open and Distributed Learning*, *19*(2), 1–15.

Fritz, C. O., Morris, P. E., & Richler, J. J. (2012). Effect size estimates: Current use, calculations, and interpretation. *Journal of Experimental Psychology. General*, *141*(1), 2–18. https://doi.org/10.1037/a0024338

Gasiewski, J. A., Eagan, M. K., Garcia, G. A., Hurtado, S., & Chang, M. J. (2012). From gatekeeping to engagement: A multicontextual, mixed method study of student academic engagement in introductory STEM courses. *Research in Higher Education*, *53*(2), 229–261. https://doi.org/10.1007/s11162-011-9247-y

Gates, A. E., & Kalczynski, M. J. (2016). The oil game: Generating enthusiasm for geosciences in urban youth in Newark, NJ. *Journal of Geoscience Education*, *64*(1), 17–23. https://doi.org/10.5408/10-164.1

Gilbert, L. A., Stempien, J., McConnell, D. A., Budd, D. A., van der Hoeven Kraft, K. J., Bykerk-Kauffman, A., Jones, M. H., Knight, C. C., Matheney, R. K., Perkins, D., & Wirth, K. R. (2012). Not just "rocks for jocks": Who are introductory geology students and why are they here? *Journal of Geoscience Education*, *60*(4), 360–371. https://doi.org/10.5408/12-287.1

Gosselin, D., Burian, S., Lutz, T., & Maxson, J. (2016). Integrating geoscience into undergraduate education about environment, society, and sustainability using place-based learning: Three examples. *Journal of Environmental Studies and Sciences*, *6*(3), 531–540. https://doi.org/10.1007/s13412-015-0238-8

Gosselin, D. C., Manduca, C. A., Bralower, T., & Egger, A. E. (2019). Preparing students to address societally relevant challenges in the geosciences: The InTeGrate approach. In *Interdisciplinary teaching about Earth and the environment for a sustainable future* (pp. 3–23). Springer.

Grawe, N. D. (2018). *Demographics and the demand for higher education*. JHU Press.

Grissom, A. (2014). The effect of inquiry on student performance, perception of relevance, and situational interest in undergraduate rock and mineral labs [MS thesis]. North Carolina State University. Retrieved July 6, 2022, from https://repository.lib.ncsu.edu/bitstream/handle/1840.16/9378/etd.pdf?sequence=1

Hammerstein, S., König, C., Dreisörner, T., & Frey, A. (2021). Effects of COVID-19-related school closures on student achievement-a systematic review. *Frontiers in Psychology*, *12*, 746289. https://doi.org/10.3389/fpsyg.2021.746289

Harackiewicz, J. M., Barron, K. E., Tauer, J. M., Carter, S. M., & Elliot, A. J. (2000). Short-term and long-term consequences of achievement goals: Predicting interest and performance over time. *Journal of Educational Psychology*, *92*(2), 316–330. https://doi.org/10.1037/0022-0663.92.2.316

Harackiewicz, J. M., Barron, K. E., Tauer, J. M., & Elliot, A. J. (2002). Predicting success in college: A longitudinal study of achievement goals and ability measures as predictors of interest and performance from freshman year through graduation. *Journal of Educational Psychology*, *94*(3), 562–575. https://doi.org/10.1037/0022-0663.94.3.562

Harackiewicz, J. M., Durik, A. M., Barron, K. E., Linnenbrink-Garcia, L., & Tauer, J. M. (2008). The role of achievement goals in the development of interest: Reciprocal relations between achievement goals, interest, and performance. *Journal of Educational Psychology*, *100*(1), 105–122. https://doi.org/10.1037/0022-0663.100.1.105

Hidi, S., & Renninger, K. A. (2006). The four phase model of interest development. *Educational Psychologist*, *41*(2), 111–127. https://doi.org/10.1207/s15326985ep4102_4

Hoyer, L., & Hastie, W. W. (2022). Geoscience undergraduate students' perceptions of how field work and practical skills influence their conceptual understanding and subject interest. *Journal of Geoscience Education*, *71*(2), 158–176. https://doi.org/10.1080/10899995.2022.2110630

Huffmyer, A. S., & Lemus, U. D. (2019). Graduate TA teaching behaviors impact student achievement in a research-based undergraduate science course. *Journal of College Science Teaching*, *48*(3), 56–65. https://doi.org/10.2505/4/jcst19_048_03_56

Hulleman, C. S., Durik, A. M., Schweigert, S. A., & Harackiewicz, J. M. (2008). Task values, achievement goals, and interest: An integrative analysis. *Journal of Educational Psychology*, *100*(2), 398–416. https://doi.org/10.1037/0022-0663.100.2.398

Hulleman, C., & Harackiewicz, J. (2009). Promoting Interest and performance in high school science classes. *Science (New York, NY)*, *326*(5958), 1410–1412. https://doi.org/10.1126/science.1177067

Hulleman, C. S., Kosovich, J. J., Barron, K. E., & Daniel, D. B. (2017). Making connections: Replicating and extending the utility value intervention in the classroom. *Journal of Educational Psychology*, *109*(3), 387–404. https://doi.org/10.1037/edu0000146

Hurst, S. D. (1998). Use of "virtual" field trips in teaching introductory geology. *Computers & Geosciences*, *24*(7), 653–658. https://doi.org/10.1016/S0098-3004(98)00043-0

Jenkins, L. L. (2011). Using citizen science beyond teaching science content: A strategy for making science relevant to students' lives. *Cultural Studies of Science Education*, *6*(2), 501–508. https://doi.org/10.1007/s11422-010-9304-4

Kali, Y., & Orion, N. (1996). Spatial abilities of high-school students in the perception of geologic structures. *Journal of Research in Science Teaching*, *33*(4), 369–391. https://doi.org/10.1002/(SICI)1098-2736(199604)33:4<369::AID-TEA2>3.0.CO;2-Q

Kastens, K., & Ishikawa, T. (n.d.). *Mentally visualizing large geologic structures from field observations: A behavioral study*. Teach the Earth. https://serc.carleton.edu/NAGTWorkshops/structure04/activities/3866.html

Kitsantas, A., & Chow, A. (2007). College students' perceived threat and preference for seeking help in traditional, distributed, and distance learning environments. *Computers & Education*, *48*(3), 383–395. https://doi.org/10.1016/j.compedu.2005.01.008

Knogler, M., Harackiewicz, J. M., Gegenfurtner, A., & Lewalter, D. (2015). How situational is situational interest? Investigating the longitudinal structure of situational interest. *Contemporary Educational Psychology*, *43*, 39–50. https://doi.org/10.1016/j.cedpsych.2015.08.004

LaDue, N. D., McNeal, P. M., Ryker, K., St. John, K., & van der Hoeven Kraft, K. J. (2022). Using an engagement lens to model active learning in the geosciences. *Journal of Geoscience Education*, *70*(2), 144–160. https://doi.org/10.1080/10899995.2021.1913715

LaDue, N. D., & Pacheco, H. A. (2013). Critical experiences for field geologists: Emergent themes in interest development. *Journal of Geoscience Education*, *61*(4), 428–436.

LaDue, N., & Schwartz, J. (n.d.). *Modeling asperities with spaghetti*. Teach the Earth. https://serc.carleton.edu/teachearth/activities/181227.html.

Lark, A. M., Richmond, G., & Pennock, R. T. (2020). The influence of instructor technological pedagogical content knowledge on implementation and student affective outcomes. In *Evolution in action: Past, present and future: A Festschrift in honor of Erik D. Goodman* (pp. 551–570). Springer.

Leal Filho, W., Wall, T., Rayman-Bacchus, L., Mifsud, M., Pritchard, D. J., Lovren, V. O., Farinha, C., Petrovic, D. S., & Balogun, A.-L. (2021). Impacts of COVID-19 and social isolation on academic staff and students at universities: A cross-sectional study. *BMC Public Health*, *21*(1), 1213. https://doi.org/10.1186/s12889-021-11040-z

Lee, J., Solomon, M., Stead, T., Kwon, B., & Ganti, L. (2021). Impact of COVID-19 on the mental health of US college students. *BMC Psychology*, *9*(1), 95. https://doi.org/10.1186/s40359-021-00598-3

Lei, H., Chiu, M. M., Wang, D., Wang, C., & Xie, T. (2022). Effects of game-based learning on students' achievement in science: A meta-analysis. *Journal of Educational Computing Research*, *60*(6), 1373–1398. https://doi.org/10.1177/07356331211064543

Lenkeit Meezan, K. A., & Cuffey, K. (2012). Virtual field trips for introductory geoscience classes. *The California Geographer*, *52*, 71–88.

Liben, L. S., & Titus, S. J. (2012). The importance of spatial thinking for geoscience education: Insights from the crossroads of geoscience and cognitive science. *Geological Society of America Special Papers*, *486*(10), 51–70.

Lin, H. S., Hong, Z. R., & Chen, Y. C. (2013). Exploring the development of college students' situational interest in learning science. *International Journal of Science Education*, *35*(13), 2152–2173. https://doi.org/10.1080/09500693.2013.818261

Little, T. D. (2023). *Longitudinal structural equation modeling*. Guilford Publications.

Luft, J. A., Kurdziel, J. P., Roehrig, G. H., & Turner, J. (2004). Growing a garden without water: Graduate teaching assistants in introductory science laboratories at a doctoral/research university. *Journal of Research in Science Teaching*, *41*(3), 211–233. https://doi.org/10.1002/tea.20004

Lukes, L. A., & McConnell, D. A. (2014). What motivates introductory geology students to study for an exam? *Journal of Geoscience Education*, *62*(4), 725–735. https://doi.org/10.5408/13-110.1

Machlev, M., & Karlin, N. J. (2017). The relationship between instructor use of different types of humor and student interest in course material. *College Teaching*, *65*(4), 192–200. https://doi.org/10.1080/87567555.2017.1333080

Maltese, A. V., & Harsh, J. A. (2015). Students' pathways of entry into STEM. In K. A. Renninger, M. Nieswandt, & S. Hidi (Eds.), *Interest in mathematics and science learning* (pp. 203–223). American Educational Research Association.

Manierre, M. J., DeWaters, J., Rivera, S., & Whalen, M. (2022). An exploration of engineering instructors' pedagogical adaptations early in the COVID-19 pandemic. *Journal of Engineering Education*, *111*(4), 889–911. https://doi.org/10.1002/jee.20483

Maraffi, S., Sacerdoti, F. M., & Paris, E. (2017). Learning on gaming: A new digital game based learning approach to improve education outcomes. *US-China Education Review A*, *7*(9), 421–432.

Martindale, R. C., & Weiss, A. M. (2020). "Taphonomy: Dead and fossilized": A new board game designed to teach college undergraduate students about the process of fossilization. *Journal of Geoscience Education*, *68*(3), 265–285. https://doi.org/10.1080/10899995.2019.1693217

McConnell, D. A., & van Der Hoeven Kraft, K. J. (2011). Affective domain and student learning in the geosciences. *Journal of Geoscience Education*, *59*(3), 106–110. https://doi.org/10.5408/1.3604828

Mead, C., Buxner, S., Bruce, G., Taylor, W., Semken, S., & Anbar, A. D. (2019). Immersive, interactive virtual field trips promote science learning. *Journal of Geoscience Education*, *67*(2), 131–142. https://doi.org/10.1080/10899995.2019.1565285

Mills, R., Tomas, L., Whiteford, C., & Lewthwaite, B. (2020). Developing middle school students' interest in learning science and geology through Slowmation. *Research in Science Education*, *50*(4), 1501–1520. https://doi.org/10.1007/s11165-018-9741-8

Mitchell, M. (1993). Situational interest: Its multifaceted structure in the secondary school mathematics classroom. *Journal of Educational Psychology*, *85*(3), 424–436. https://doi.org/10.1037/0022-0663.85.3.424

Musacchio, G., Piangiamore, G. L., D'Addezio, G., Solarino, S., & Eva, E. (2015). "Scientist as a game": learning geoscience via competitive activities. *Annals of Geophysics*, *58*(3), S0328–S0328.

Nesher Shoshan, H., & Wehrt, W. (2022). Understanding "Zoom fatigue": A mixed-method approach. *Applied Psychology*, *71*(3), 827–852. https://doi.org/10.1111/apps.12360

O'Neal, C., Wright, M., Cook, C., Perorazio, T., & Purkiss, J. (2007). The impact of teaching assistants on student retention in the sciences: Lessons for TA training. *Journal of College Science Teaching*, *36*(5), 24.

Palmer, D. H. (2009). Student interest generated during an inquiry skills lesson. *Journal of Research in Science Teaching*, *46*(2), 147–165. https://doi.org/10.1002/tea.20263

Palmer, D. H., Dixon, J., & Archer, J. (2016). Identifying underlying causes of situational interest in a science course for preservice elementary teachers. *Science Education*, *100*(6), 1039–1061. https://doi.org/10.1002/sce.21244

Palmer, D., Dixon, J., & Archer, J. (2017). Using situational interest to enhance individual interest and science-related behaviours. *Research in Science Education*, *47*(4), 731–753. https://doi.org/10.1007/s11165-016-9526-x

Park, C. (2004). Neither fish nor fowl? The perceived benefits and problems of graduate teaching assistants (GTAs) to teach undergraduate students. *Higher Education Review*, *35*(1), 50–62.

Pelch, M. A., & McConnell, D. A. (2017). How does adding an emphasis on socioscientific issues influence student attitudes about science, its relevance, and their interpretations of sustainability? *Journal of Geoscience Education*, *65*(2), 203–214. https://doi.org/10.5408/16-173.1

Piper, M., Frankle, J., Owens, S., Stubbins, B., Tully, L., & Ryker, K. (2024). A review of the inquiry and utility of mineral and rock labs for use in introductory geology courses. *Journal of Geoscience Education*, 1–11. https://doi.org/10.1080/10899995.2024.2305981

Piper, M., Ryker, K., Bitting, K., & Teasdale, R. (2022). Engaging students in the scientific process: A case study of inquiry within five introductory geology courses [conference presentation]. In Earth Educators Rendezvous Conference.

Plenge, M. F., Hutson, B. L., & Graniero, L. E. (2022). The BeAMS project: Using inquiry and modeling to introduce students to the research process in an introductory geology laboratory. *Journal of Geoscience Education*, *70*(3), 368–383. https://doi.org/10.1080/10899995.2021.1951080

Price Banks, D., & Vergez, S. M. (2022). Online and In-person learning preferences during the COVID-19 pandemic among students attending the City University of New York. *Journal of Microbiology & Biology Education*, *23*(1), e00012. https://doi.org/10.1128/jmbe.00012-22

Qayyum, A. (2018). Student help-seeking attitudes and behaviors in a digital era. *International Journal of Educational Technology in Higher Education*, *15*(1), 1–16. https://doi.org/10.1186/s41239-018-0100-7

Quak, M., London, R. E., & Talsma, D. (2015). A multisensory perspective of working memory. *Frontiers in Human Neuroscience*, *9*, 197. https://doi.org/10.3389/fnhum.2015.00197

Rapp, D. N., Culpepper, S. A., Kirkby, K., & Morin, P. (2007). Fostering students' comprehension of topographic maps. *Journal of Geoscience Education*, *55*(1), 5–16. https://doi.org/10.5408/1089-9995-55.1.5

Renninger, K. A., & Hidi, S. E. (2016). *The power of interest for motivation and engagement*. Routledge.

Renninger, K. A., & Lipstein, R. (2006). Developing interest for writing: What do students want and what do students need? *Eta Evolutiva*, *84*, 65–83.

Renninger, K. A., Nieswandt, M., & Hidi, S. (2015). *Interest in mathematics and science learning*. American Educational Research Association.

Renninger, K. A., & Hidi, S. E. (2019). Interest development and learning. In K. A. Renninger & S. E. Hidi (Eds.), *The Cambridge handbook of motivation and learning* (pp. 265–296). Cambridge University Press.

Renninger, K., & Su, S. (2019). Interest and its development, revisited. In R. M. Ryan (Ed.), *Oxford handbook of human motivation* (2nd ed.). Oxford Library of Psychology.

Robertson, W. M. (2022). Increasing student engagement and comprehension of the global water cycle through game-based learning in undergraduate courses. *Journal of Geoscience Education*, *70*(2), 161–175. https://doi.org/10.1080/10899995.2021.1977030

Rotgans, J. I., & Schmidt, H. G. (2017). Interest development: Arousing situational interest affects the growth trajectory of individual interest. *Contemporary Educational Psychology*, *49*, 175–184. https://doi.org/10.1016/j.cedpsych.2017.02.003

Rowe, R. J., Koban, L., Davidoff, A. J., & Thompson, K. H. (2018). Efficacy of online laboratory science courses. *Journal of Formative Design in Learning*, *2*(1), 56–67. https://doi.org/10.1007/s41686-017-0014-0

Salter, S., & Gardner, C. (2016). Online or face-to-face microbiology laboratory sessions? First year higher education student perspectives and preferences. *Creative Education*, *7*(14), 1869–1880. https://doi.org/10.4236/ce.2016.714189

Schank, R. C. (1979). Interestingness: Controlling inferences. *Artificial Intelligence*, *12*(3), 273–297. https://doi.org/10.1016/0004-3702(79)90009-2

Semken, S., Ward, E. G., Moosavi, S., & Chinn, P. W. (2017). Place-based education in geoscience: Theory, research, practice, and assessment. *Journal of Geoscience Education*, *65*(4), 542–562. https://doi.org/10.5408/17-276.1

Sherman-Morris, K., & McNeal, K. S. (2016). Understanding perceptions of the geosciences among minority and nonminority undergraduate students. *Journal of Geoscience Education*, *64*(2), 147–156. https://doi.org/10.5408/15-112.1

Sprague, J., & Stuart, D. (2000). *The speaker's handbook. Ft*. Hartcourt Brace & Company.

St. John, K., & Callahan, J. (2003). Making geology relevant to non-science majors through the environmental site assessment project. *Journal of Geoscience Education*, *51*(4), 431–435. https://doi.org/10.5408/1089-9995-51.4.431

Steele, C. M., & Aronson, J. (1995). Stereotype threat and the intellectual test performance of African Americans. *Journal of Personality and Social Psychology*, *69*(5), 797–811. https://doi.org/10.1037/0022-3514.69.5.797

Sundberg, M. D., Armstrong, J. E., & Wischusen, E. W. (2005). A reappraisal of the status of introductory biology laboratory education in U.S. colleges and universities. *The American Biology Teacher*, *67*(9), 525–529. https://doi.org/10.2307/4451904

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*(2), 257–285. https://doi.org/10.1207/s15516709cog1202_4

Teach the Earth. (n.d.). Teaching with online field experiences. Retrieved June 22, 2023, from https://serc.carleton.edu/NAGTWorkshops/online_field/index.html.

Teasdale, R., Bitting, K., & Ryker, K. (Eds.). (2021a). *Guided inquiry introductory geology labs*. Retrieved July 6, 2022, from https://serc.carleton.edu/inquiry_intro_geo/index.html.

Teasdale, R., Scherer, H., Holder, L., Boger, R., & Forbes, C. (2018a). Research on teaching about earth in the context of societal problems. In K. St. John (Ed.), *Community framework for geoscience education research*. National Association of Geoscience Teachers. https://doi.org/10.25885/ger_framework/5

Teasdale, R., Selkin, P., & Goodell, L. (2018b). Evaluation of student learning, self-efficacy, and perception of the value of geologic monitoring from Living on the Edge, an InTeGrate curriculum module. *Journal of Geoscience Education*, *66*(3), 186–204. https://doi.org/10.1080/10899995.2018.1481354

Teasdale, R., van der Hoeven Kraft, K., & Poland, M. P. (2015). Using near-real-time monitoring data from Pu'u' O'o vent at Kīlauea Volcano for training and educational purposes. *Journal of Applied Volcanology*, *4*(1), 1–16. https://doi.org/10.1186/s13617-015-0026-x

Teasdale, R., Bitting, K., & Ryker, K. (2021b). Student and teaching assistants' perspectives on increasing student interest for learning in introductory geology courses. In GSA Connects, 12 October.

Thacker, I., Seyranian, V., Madva, A., & Beardsley, P. (2022). STEM faculty's support of togetherness during mandated separation: Accommodations, caring, crisis management, and powerlessness. *Education Sciences*, *12*(9), 632. https://doi.org/10.3390/educsci12090632

Theobald, E. J., Hill, M. J., Tran, E., Agrawal, S., Arroyo, E. N., Behling, S., Chambwe, N., Cintrón, D. L., Cooper, J. D., Dunster, G., Grummer, J. A., Hennessey, K., Hsiao, J., Iranon, N., Jones, L., Jordt, H., Keller, M., Lacey, M. E., Littlefield, C. E., … Freeman, S. (2020). Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math. *Proceedings of the National Academy of Sciences of the United States of America*, *117*(12), 6476–6483. https://doi.org/10.1073/pnas.1916903117

Thompson, C., & Henson, K. (2021). Comparing virtual and face-to-face forensic science labs. *Proceedings of the West Virginia Academy of Science*, *93*(1). https://doi.org/10.55632/pwvas.v93i1.749

Trend, R. (2005). Individual, situational and topic interest in geoscience among 11-and 12-year-old children. *Research Papers in Education*, *20*(3), 271–302. https://doi.org/10.1080/02671520500193843

van der Hoeven Kraft, K. J. (2017). Developing student interest: An overview of the research and implications for geoscience education research and teaching practice. *Journal of Geoscience Education*, *65*(4), 594–603. https://doi.org/10.5408/16-215.1

van Der Hoeven Kraft, K. J., Srogi, L., Husman, J., Semken, S., & Fuhrman, M. (2011). Engaging students to learn through the affective domain: A new framework for teaching in the geosciences. *Journal of Geoscience Education*, *59*(2), 71–84. https://doi.org/10.5408/1.3543934a

Verduyn, P., Ybarra, O., Résibois, M., Jonides, J., & Kross, E. (2017). Do social network sites enhance or undermine subjective well-being? A critical review. *Social Issues and Policy Review*, *11*(1), 274–302. https://doi.org/10.1111/sipr.12033

Wade, S. E., Schraw, G., Buxton, W. M., & Hayes, M. T. (1993). Seduction of the strategic reader: Effects of interest on strategies and recall. *Reading Research Quarterly*, *28*(2), 92. https://doi.org/10.2307/747885

Wang, X., Hegde, S., Son, C., Keller, B., Smith, A., & Sasangohar, F. (2020). Investigating mental health of US college students during the COVID-19 pandemic: Cross-sectional survey study. *Journal of Medical Internet Research*, *22*(9), e22817. https://doi.org/10.2196/22817

Wang, J., Mann, F., Lloyd-Evans, B., Ma, R., & Johnson, S. (2018). Associations between loneliness and perceived social support and outcomes of mental health problems: A systematic review. *BMC Psychiatry*, *18*(1), 156. https://doi.org/10.1186/s12888-018-1736-5

Warner, D. B., & Koeppel, K. (2009). General education requirements: A comparative analysis. *The Journal of General Education*, *58*(4), 241–258. https://doi.org/10.2307/25702446

Wildan, W., Hakim, A., Siahaan, J., & Anwar, Y. A. S. (2019). A stepwise inquiry approach to improving communication skills and scientific attitudes on a biochemistry course. *International Journal of Instruction*, *12*(4), 407–422. https://doi.org/10.29333/iji.2019.12427a

Wolf-Wendel, L., Twombly, S. B., & Rice, S. (2004). *The two-body problem: Dual-career-couple hiring practices in higher education*. JHU Press.

Yates, D., Moore Moore, D., & McCabe, G. (1999). *The practice of statistics* (1st ed.) W.H. Freeman.

Yuretich, R. F., Khan, S. A., Leckie, R. M., & Clement, J. J. (2001). Active-learning methods to improve student performance and scientific interest in a large introductory oceanography course. *Journal of Geoscience Education*, *49*(2), 111–119. https://doi.org/10.5408/1089-9995-49.2.111