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On-Campus Field Experiences Help Students to Learn and Enjoy Water Science During the COVID-19 Pandemic

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Online modes of teaching and learning have gained increased attention following the COVID-19 pandemic, resulting in education delivery trends likely to continue for the foreseeable future. It is therefore critical to understand the implications for student learning outcomes and their interest in or affinity towards the subject, particularly in water science classes, where educators have traditionally employed hands-on outdoor activities that are difficult to replicate online. In this study, we share our experiences adapting a field-based laboratory activity on groundwater to accommodate more than 700 students in our largest-enrollment general education course during the pandemic. As part of our adaptation strategy, we offered two versions of the same exercise, one in-person at the Mirror Lake Water Science Learning Laboratory, located on Ohio State University's main campus, and one online. Although outdoor lab facilities have been used by universities since at least the 1970s, this research is novel in that 1) it considers not only student achievement but also affinity for the subject, 2) it is the first of its kind on The Ohio State University's main campus, and 3) it was conducted during the COVID-19 pandemic, at a time when most university classes were unable to take traditional field trips. We used laboratory grades and a survey to assess differences in student learning and affinity outcomes for in-person and online exercises. Students who completed the in-person exercise earned better scores than their online peers. For example, in Fall 2021, the median lab score for the in-person group was 97.8%, compared to 91.7% for the online group. The in-person group also reported a significant ($p < 0.05$) increase in how much they enjoyed learning about water, while online students reported a significant decrease. Online students also reported a significant decrease in how likely they would be to take another class in water or earth sciences. It is unclear whether the in-person exercise had better learning and affinity outcomes because of the hands-on, outdoor qualities of the lab or because the format allowed greater interaction among peers and teaching instructors (TAs). To mitigate disparities in student learning outcomes between the online and in-person course delivery, instructors will implement future changes to the online version of the lab to enhance interactions among students and TAs.

Keywords: hydrogeology, geoscience education, pandemic, laboratory, groundwater

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INTRODUCTION

The COVID-19 pandemic forced a shift towards online teaching and learning, where educators at every level initially operated in "triage mode" (Kilpatrick et al., 2021). Large numbers of faculty who had never taught online (and/or had never taken classes online) were suddenly responsible for teaching students exclusively online. Moreover, most students were also unfamiliar with the administration of classes in an online setting. This sudden shift in online learning exacerbated systemic barriers for students (e.g., students with weaker academic backgrounds learn better in face-to-face classes, and internet/technology access is not evenly distributed). The lack of instructor and peer interaction and feedback also resulted in sharp decreases in student satisfaction (Kanetaki et al., 2021; Sahu 2020; McCarthy 2020; Zhai and Xue 2020). Although in-person teaching restrictions eventually eased with the development of university health and safety protocols, online education will remain a component of educational models for the foreseeable future. It is therefore critical to understand the implications for student learning and their interest in or affinity towards the subject matter.

It is well documented that students are more likely to master course content when they are active participants in their learning. Experiential learning theory suggests that active participation and outcome observation lead to greater conceptual understanding and longer-term retention of course content (Kolb 2015). These learning experiences often include multisensory integration, which allows the brain to process and integrate new information more effectively to facilitate longer-term learning (Persellin and Daniels 2015). Of note, inquiry-based exercises enhance learning by fostering critical thinking and problem-solving skills (Duran and Dökme 2016). Furthermore, field-based exercises provide effective opportunities for students to integrate course material with hands-on field experiences (Trop et al., 2000; Salvwage et al., 2004; Dripps 2019). These types of exercises are especially important in STEM classes, where poor teaching methods are the primary reason that students abandon STEM majors within their first 2 years of higher education (Seymour and Hewitt 1997).

Since at least the 1970s, college campuses have created and used outdoor laboratory spaces as a strategy for providing students with field-based training in STEM subjects (Lawrence, 1975), and their use has continued to grow (Berman et al., 2008; Schwartz 2013). In water sciences, a subject that deals almost exclusively with outdoor processes, instructors have gravitated toward the chance to move teaching from traditional indoor classrooms to outdoor spaces (Hakoun et al., 2013; Van Loon, 2019). In ideal scenarios, outdoor lab spaces are located within walking distance of classrooms, providing easy access within the relatively short lecture and laboratory periods (e.g., (Oliver et al. 2018). The myriad learning benefits these facilities offer students are well-documented and remain a potential socially distanced option for instructors to grant students hands-on learning experiences.

The Mirror Lake Water Science Outdoor Laboratory is a multi-use outdoor training facility for earth science and hydrology students in the heart of The Ohio State University (OSU) main campus (**Figure 1**). It occupies the South Oval and areas around Mirror Lake, a recently restored lake that has been an iconic recreational space for almost 150 years. The outdoor laboratory facility includes a network of wells and two telemetered sensors that continuously stream water quality data for the lake and groundwater (**Figure 1**). Thanks to its central location on campus and outdoor setting, the Mirror Lake Water Science Outdoor Laboratory was one of the few sites where earth science students could develop new field skills during the pandemic, particularly early in the Fall 2020 (FA20) semester. Our motivation for this research is to enhance learning and engagement for introductory earth science students. Specifically, the goal of this paper is to share our experiences following an adaptation of a field-based laboratory activity at Mirror Lake to accommodate over 700 students in our largest-enrollment general education course during the pandemic. Although the benefits of hands-on, field-based training have been well-documented, this research is unique in that 1) it considers both student achievement and affinity for the course subject, 2) it is the first of its kind on The Ohio State University's main campus, and 3) it was conducted during the COVID-19 pandemic, enabling us to assess student performance and

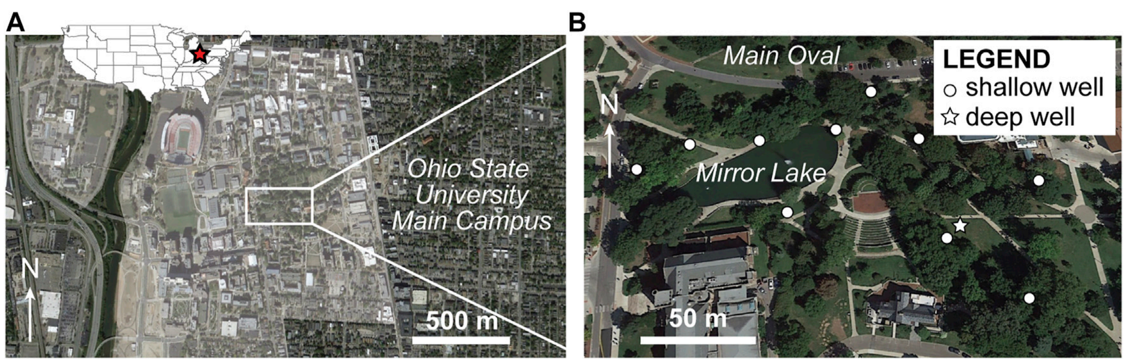

FIGURE 1 | (A) Map of Ohio State University Main Campus in Columbus, Ohio. **(B)** Location of the Mirror Lake Water Science Learning Lab, which hosts ten shallow wells and one deep well for educational activities.

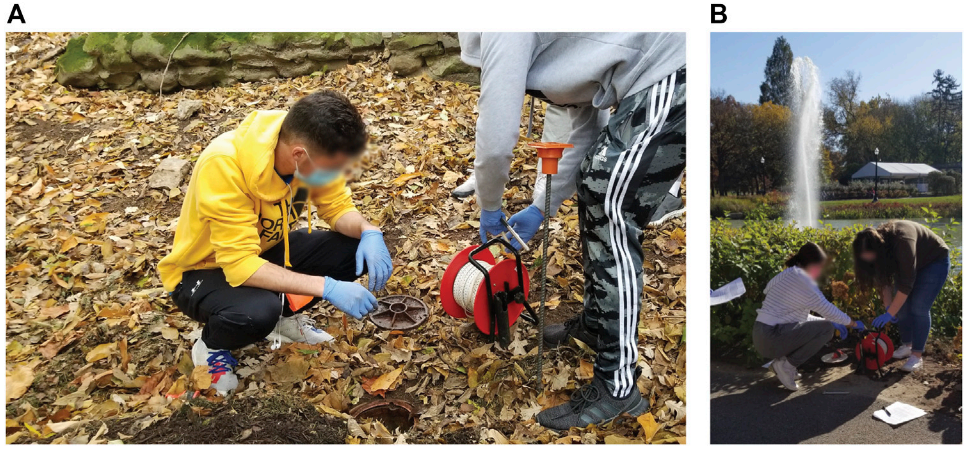

FIGURE 2 | (A, B) Students in general education class ES 1200: Introductory Earth Science Lab used a beep tape to measure depth to water in shallow wells during the pandemic. Masks were required for participation, and laboratory gloves were provided. Photographer: Rowan McLachlan.

perceptions in response to laboratory adaptations made during a pandemic. As part of our adaptation strategy, we offered two versions of the same laboratory exercise, one in-person and one online. Below, we begin by describing the outdoor laboratory facility and the laboratory exercise, including our health and safety adaptations. Next, we examine scores on the in-person and online laboratory exercises to compare learning outcomes for both instruction modes. We then evaluate the impact of both instruction modes on students' affinities for water science using surveys that were conducted in Fall 2021 (FA21). Finally, we offer lessons learned and recommendations for pandemic teaching in similar outdoor laboratory facilities.

MATERIALS AND METHODS

Mirror Lake Water Science Learning Laboratory

The Mirror Lake Water Science Learning Laboratory (**Figure 1**) was established in 2018 to provide more accessible space where students could learn hands-on field skills in hydrology and hydrogeology. An additional goal of the space is to connect students with professionals who can share their experiences in the geoscience workforce. Guest lecturers from local consulting firms and government agencies regularly co-lead laboratory activities with Ohio State University faculty and teaching assistants (TAs).

The Learning Lab is used by almost 1,000 students each semester in general education, major-specific, and graduate-level earth science classes. Students in general education exercises learn to make water level measurements in wells (**Figure 2**) and contour the results to interpret directions of groundwater flow. They also measure water quality, including dissolved oxygen and nutrient levels, in both lake water and groundwater. Students in upper-level and graduate classes use the site for aquifer testing, borehole logging, and ground-based geophysical surveys. Because the Learning Lab is a multi-use space in the heart of the main campus, it is accessible for short lecture demonstrations as well as full-length laboratory exercises. No vans are needed for transportation, and all the wells are accessible from walkways.

The space includes a network of 10 shallow wells with 2″ casing ranging in depth from approximately 5–9 m (**Figures 1**, **2**). A deeper, 8" well was also drilled to an approximate depth of 36 m. The deep well and the lake are both equipped with telemetered sensors that monitor pressure, temperature, and fluid electrical conductivity every 15 min (https://mirrorlake.byrd.osu.edu/). A campus rain gauge also records daily rainfall totals approximately 600 m from the site.

Laboratory Design and Pandemic Modifications for a General-Education Exercise

The introductory groundwater laboratory exercise at Mirror Lake is taught as part of ES (Earth Science) 1,200: Introductory Earth Science Laboratory, a 1-credit course that satisfies OSU's general education requirements for natural science. The goals of the exercise are to introduce students to basic concepts of groundwater as a resource, groundwater flow, and contour mapping. Students first complete a pre-lab exercise with a short reading and video about groundwater resources and several questions that are intended to reinforce their comprehension. They then measure water levels in 10 piezometers in Mirror Lake and use measurements to produce a contour map of the water table near the lake. The students interpret whether lake water is recharging the aquifer or groundwater is discharging to the lake based on their contour map. Laboratory materials are available through CUAHSI HydroShare (https://www.hydroshare.org/resource/7f6295a88f2743a58e3447db650df0d2/).

Prior to the COVID-19 pandemic, ES 1200 was an in-person class, and all laboratory exercises were taught in small sections of up to 30 students. In response to the pandemic, two versions of ES 1200 were offered to students in the autumn semester of 2020

TABLE 1 | Study structure, including relevant questions, data sources, semesters, and numbers of participants.

How do in-person versus online lab experiences affect student academic performance and learning outcomes?			
Test	**Semester**	**# Online**	**# In-Person**
Control: Pre-Lab Quiz (overall grade, % correct on 1 multiple-choice question)	FA 20	171	205
	SP 21	0	781
	FA 21	36	491
Experiment: Lab Activity (overall grade, % correct on 2 multiple-choice questions)	FA 20	171	205
	SP 21	0	781
	FA 21	36	491
How do in-person vs. online lab experiences affect student affinity for earth and water science?			
Test	**Semester**	**# Online**	**# In-person**
Control: Pre-Lab Affinity Survey	FA 21	16	306
Experiment: Post-Lab Affinity Survey	FA 21	22	264

(FA20): online and in-person. Laboratory exercises that could not easily be adapted for both formats were replaced. The groundwater laboratory exercise remained and was the only exercise that offered in-person participants a field experience that semester. We designed this study to assess differences in learning outcomes and affinity for water science between the two groups that completed the in-person and online versions of the groundwater exercise, using the study structure in **Table 1**.

To adapt the in-person version of the lab for the pandemic, the following modifications were made. Students feeling ill or in quarantine/isolation were permitted to complete the lab online with no penalty. Students able to attend the lab in-person met in a socially distanced indoor classroom and were required to wear laboratory gloves and face masks. Students were provided with a brief introduction to the topic and the lab activity by an in-class TA. Following the introduction, students ventured outside to locate the groundwater wells and measure groundwater levels. Measurements were recorded on printed datasheets. Upon completion of the activity (~ 30–45 min), students returned to the indoor classroom to complete the contour map and answer questions. In FA20, most in-person students completed printed handouts of the lab questions during the assigned lab time, but they also had access to the questions through OSU's online Learning Management System (LMS) if they desired to continue working on the exercise after their assigned lab time.

The online version of the exercise was offered asynchronously. Online participants were assigned a Teaching Assistant (TA) who was available for questions through email contact and online office hours. In the online exercise, students were asked to watch a short video of another student measuring depth to water in one of the Mirror Lake wells. Students were provided with photographs of each well showing where the measuring tape intersected the well casing on a previous date. Students were then asked to read the depth-to-water for each well from the photographs. They then used these measurements to make a contour map and answer the same interpretive questions as the in-person participants, submitting their answers through the online Learning Management System. Online students had the same assignment deadline as in-person students (the end of the lab week). They were encouraged to reach out to a TA *via* email or during office hours if they encountered difficulties completing the exercise. Both online and in-person groups also had access to an "Additional Resources" page with helpful links and hints to aid in the completion of the lab.

In the spring semester of 2021 (SP21), all ES 1200 lab sections were online due to a variety of considerations associated with limitations in TA staffing and the increasing COVID infections on campus. No students completed the in-person version of the groundwater lab exercise that semester. In the autumn semester of 2021 (FA21), all ES 1200 lab sections were in-person due to ample TA staffing and encouraging COVID trends. However, students who needed to quarantine or had other extenuating circumstances that prevented them from safely participating in the groundwater lab exercise were offered the online version of the exercise for full credit. As before, both the in-person and the online students were provided with the same deadline and submitted their exercises through the online LMS.

Assessing Learning Outcomes Through Lab Scores

We analyzed pre-lab questions to identify whether the in-person and online groups were statistically similar in terms of their groundwater knowledge before participating in the lab (**Table 1**). In FA21, in-person groups completed the pre-lab questions in front of TAs before taking their field measurements, so they may have benefitted from extra TA support. We therefore only compared pre-lab performance for the FA20 semester. We discarded one open-ended question from the analysis because the scores were influenced by the individual grading style of each TA. We analyzed the percentage of correct answers for the combined remaining 5 multiple-choice questions. We also examined the fraction of students who correctly answered one multiple choice question that we deemed representative of pre-lab concepts. This question was related to a news segment in a video and asked, "How long does it typically take for a deeper aquifer to recharge?" Chi-square tests were conducted to determine statistically significant differences between the percentage of correct answers in online and in-person groups.

To assess comprehension after the lab exercise (**Table 1**), we examined the distributions of total lab exercise scores and performed a Welch's t-test to test for statistically significant differences between scores. Due to the unequal variances between compared means, Welch's t-test was used rather than

Student's t-test. We also examined two specific questions that targeted students' comprehension of their contour maps: "Is hydraulic head generally greater in the piezometers (wells) or the lake (overlook)?" and "Is groundwater discharging to the lake or is lake water infiltrating into the ground?" These questions were multiple choice. Students could not receive partial credit. Chi-square tests were conducted to test statistically significant differences between percentage correctness.

Assessing Affinity Outcomes Through Surveys

During FA21, students were provided a pre- and post-lab survey through the online Learning Management System to gauge their affinity for the topic of groundwater (**Supplementary Appendix SA**). The pre-lab survey acted as a control to gauge initial interest (**Table 1**) and asked for basic student information, including their major and class rank (i.e., first-year, second-year). The post-lab survey repeated the same questions on interest and posed additional open-ended questions including "What did you enjoy most about this lab" and "What would you do to improve this lab?"

The four affinity questions used a Likert scale (i.e., Strongly Disagree—Strongly Agree) to assess identical ideas before and after the lab activity, including: 1) how much they thought about groundwater in the past (pre-lab) and how much they might think about it in the future (post-lab); 2) how much they enjoyed learning about water (pre- and post-lab); 3) how interested they were in taking another earth or water science class (pre- and post-lab); and 4) whether they saw themselves in a water-related or earth science-related career (pre- and post-lab). Likert scale data was scored from 1 (Strongly Disagree) to 5 (Strongly Agree) for statistical analysis. Differences in lab experience were assessed using a Welch's t-test between mean scores for each of the four survey questions between 1) pre- and post-lab online surveys, 2) pre- and post-lab in-person surveys, and 3) post-lab online and in-person surveys. Multiple variances between compared means were >1, leading to the use of the Welch's t-test rather than the Student's t-test for evaluating the statistical significance of the Likert scale questions. Additionally, to assess whether pre-existing differences in the online and in-person student populations (rather than lab experience) affect our results, pre-lab surveys for online and in-person students were separated for comparison.

To analyze what students most enjoyed about the labs, responses were reviewed and grouped into 8 distinct categories. The number of responses that fell under each category was then tallied.

RESULTS

Learning Outcomes

In FA20, 205 students completed the in-person assignment, while 171 students completed the online assignment. In SP21, 781 students completed the online assignment. In FA21, 491 students completed the in-person lab assignment, while 36 students completed the online assignment. In FA20, TAs were highly encouraged to reward participation and grade for completion to alleviate some of the stress on students during the pandemic. As a result, total lab scores for in-person and online students both had a median of 100% (**Figure 3A**). The variability was greater for in-person students, but this variability can be explained by differences in TAs (each TA had a unique interpretation of what it meant to grade for participation and completion). To account for these differences, we compared scores among groups of in-person and online students who had the same TA (**Figure 3B**). For most TAs (10/12) with an in-person and online section, the in-person students scored better. In FA21, the TAs were not asked to grade only for participation and completion, and the differences in lab grades were clear, irrespective of TAs. In-person students out-performed online students ($p < 0.001$), with a median of 97.78% compared to that of 91.67% for online students (**Figure 3A**).

In the pre-lab control, students performed similarly well, regardless of the delivery mode, suggesting there were no initial differences in knowledge or performance between in-person and online groups. In FA20, average cumulative pre-lab scores on the five multiple-choice questions were 94.79% for in-person students and 94.24% for online students ($p > 0.05$). Students performed similarly on the question "How long does it typically take for a deeper aquifer to recharge?" In FA20, the rate of correct answers was 97.34% in-person group and 97.12% in the online group (a difference of <1%) (**Figure 4A**).

In comparison, the performance gap was greater for the two interpretative questions at the end of the lab (**Figure 4B**). For the first question ("Is hydraulic head generally greater in the piezometers (wells) or the lake (overlook)?") in FA20, 78.54% of in-person students and 74.85% of online students had the correct answers ($p > 0.05$). In FA21, 98.78% of in-person students and 97.22% of online students had the correct answers ($p > 0.05$) (**Figure 4B**). The same conclusion was drawn for the second question "Is groundwater discharging to the lake or is lake water infiltrating into the ground?" In FA20, 78.05% of in-person students and 74.27% of online students had the correct answers ($p > 0.05$). In FA21, 96.13% of in-person students and 86.11% of online students had the correct answers ($p < 0.05$) (**Figure 4C**). It is worth noting that incorrect answers came mostly from students who had both incorrect measurements and inconsistent interpretations of those measurements. Less than <10% of students who answered wrong on the first question (**Figure 4B**) had simply misinterpreted good measurements. Another 20% had interpretations that were wrong but consistent with their (incorrect) measurements.

Affinity Outcomes

Pre-lab affinity surveys were completed by a total of 306 in-person students and 16 online students. Post-lab affinity surveys were completed by 264 in-person students and 22 online students. Responses to Likert scale questions in these surveys suggest in-person and online students had different experiences during the lab exercise. While in-person respondents' average affinity (i.e., average levels of agreement to questions) for learning about water significantly increased ($p < 0.001$) following the lab exercise, online students' average affinity significantly decreased (**Figure 5**). Specifically, online students' interest in taking another

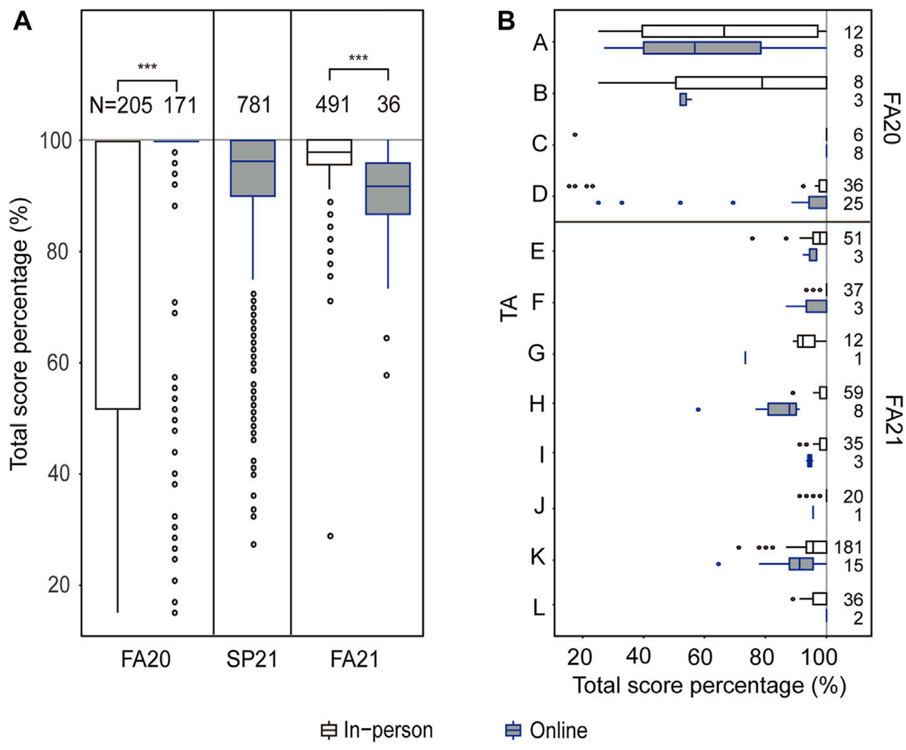

FIGURE 3 | (A) Total lab score percentages by semester, regardless of TA. **(B)** Total lab score percentages by TA, only for those TAs who instructed students using in-person and online modes.

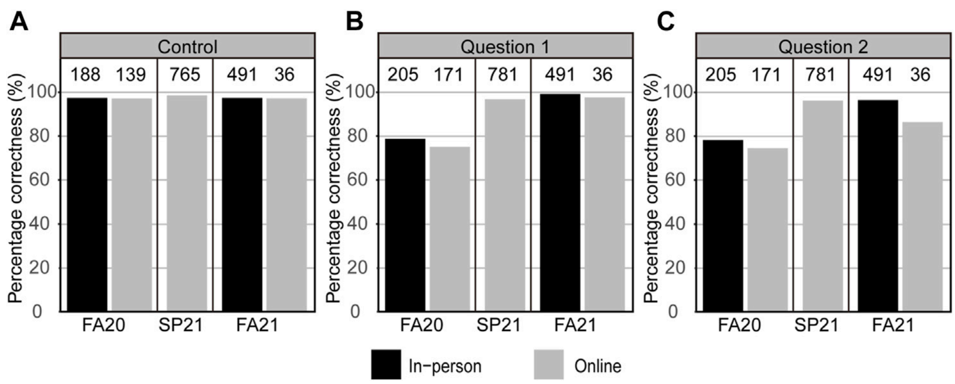

FIGURE 4 | Percentage of students with correct answers for three representative questions **(A)** Pre-lab Control: How long does it typically take for deeper aquifer to recharge? **(B)** Question 1: Is hydraulic head generally greater in the piezometers (wells) or the lake (overlook)? **(C)** Question 2: Is groundwater discharging to the lake, or is lake water infiltrating into the ground?.

class in earth or water science significantly decreased, and they expected they would think significantly less about groundwater in the future (**Figure 5**). Though not statistically significant ($p > 0.05$), more in-person students envisioned themselves in a water- or earth science-related career after participating in the lab, while fewer online students did (**Figure 5**).

Conclusions about online students may be limited by the small sample size, both for pre-lab and post-lab surveys. In FA21, students were only approved for an online version of the exercise if they were absent due to sickness, quarantine, or other reasons that their instructor felt prevented them from attending a different in-person section. As a result, online students may have had personal factors that limited the time and energy they were able to devote to the lab assignment when compared to in-person students. Although online students report slightly lower affinity levels than in-person students in

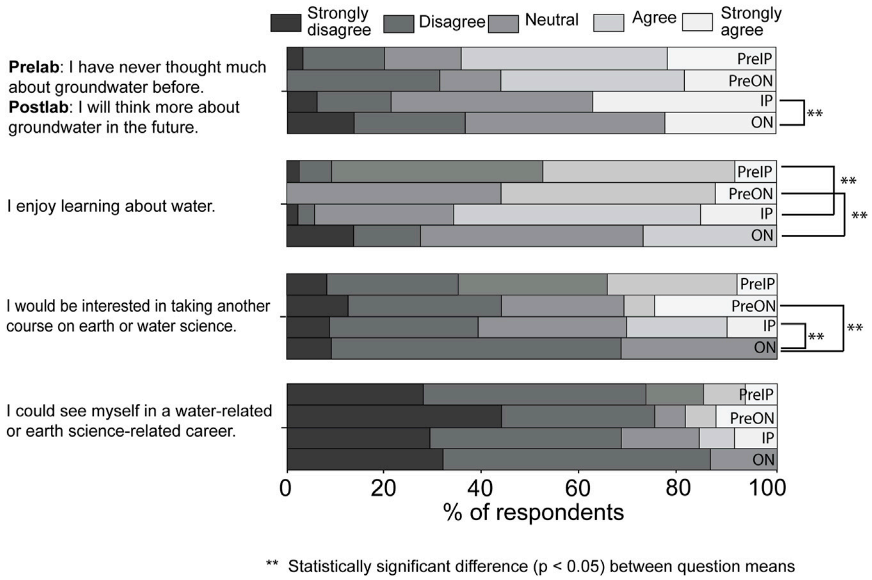

FIGURE 5 | Comparison of responses to Likert-scale questions on affinity from the pre-lab survey of in-person students (PreIP, $n = 306$), the pre-lab survey of online students (PreON, $n = 16$), the post-lab survey of in-person students (IP, $n = 264$) and the post-lab survey of online students (ON, $n = 22$). Statistical significance at the 95% confidence level was evaluated using a Welch's t-test (allowing for unequal variances) between the mean Likert score among responses for each survey question.

the pre-lab survey, the difference is not statistically significant (**Figure 5**). Therefore, we attribute differences from the pre- and post-lab surveys primarily to differences in lab experience. For example, although the online and in-person students were given similar instructional text in the lab assignments, many online students (~ 59%) indicated that they felt the lab assignment needed more information and instructions, suggesting a major difference in perception of the exercise. In comparison, only 31 of the 264 (~ 12%) in-person students offered similar feedback.

Eighteen of the 22 online students provided detailed information about what they enjoyed most in the lab exercise. Eight respondents (~ 44%) enjoyed the "subject covered," 4 respondents (~ 22%) provided negative feedback to the question, and 6 respondents (~ 33%) had diverse answers scattered throughout the remaining categories. Two-hundred-fifty-three of the 264 in-person students offered responses to this question. One-hundred-eighty respondents (~ 71%) enjoyed the "outside and hands-on" aspect of the lab activity. Of the remaining 84 respondents, 43 (~17%) enjoyed the "subject covered," 19 (~ 7%) enjoyed the "group work," and 11 (~ 4%) had diverse answers scattered throughout the five remaining categories, all with three responses or less (**Figure 6**). It is worth noting that ~ 70% of respondents were non-STEM majors, ~ 28% were STEM majors, and 2% were undecided. 23% of respondents were first-year students, 36% were second-year students, 36% were third-year students, and 5% were fourth-year students.

DISCUSSION

Our results suggest that hands-on learning activities with in-person peer and instructor feedback can improve grades for students in earth and water sciences and can increase their affinity for the subject. This is consistent with literature demonstrating that experiential learning in earth sciences improves student engagement and academic performance (Olcott 2018). Providing this hands-on experience was possible due to the existence of accessible outdoor laboratory space. The benefits of outdoor learning spaces, particularly those which facilitate hands-on, inquiry-based learning are well documented (Trop, Krockover, and Ridgway 2000; Salvage, Graney, and Barker 2004; Dripps 2019). This study provides further evidence that by investing in multi-use outdoor laboratory spaces, universities can inspire students' enthusiasm for STEM and make it easier for them to grasp difficult scientific concepts. The importance of outdoor lab spaces was particularly illustrated during the pandemic when classes could not access more distant field sites due to restrictions on group transportation. The Mirror Lake Water Science Learning Laboratory's on-campus location and proximity to lecture buildings make it an ideal outdoor learning space for students to gain experience in the water sciences. The space also addresses sustainability goals stated in the university's Sustainability Goals Project Report, to "integrate teaching, research, and operations through learning-by-doing approaches, including project-based service-learning, utilizing campus as a testbed and other research activities to expand sustainability efforts across and beyond campus."

It is possible that the hands-on activity itself was not the reason for greater comprehension and increases in affinity, but rather the structured access to TAs and peers in the in-person sections. As an example, a consistently challenging task for many students in this lab activity was contour mapping. From an instructor's perspective, the concept can be difficult to explain in a "one-size-fits-all" way during lecture since the steps required

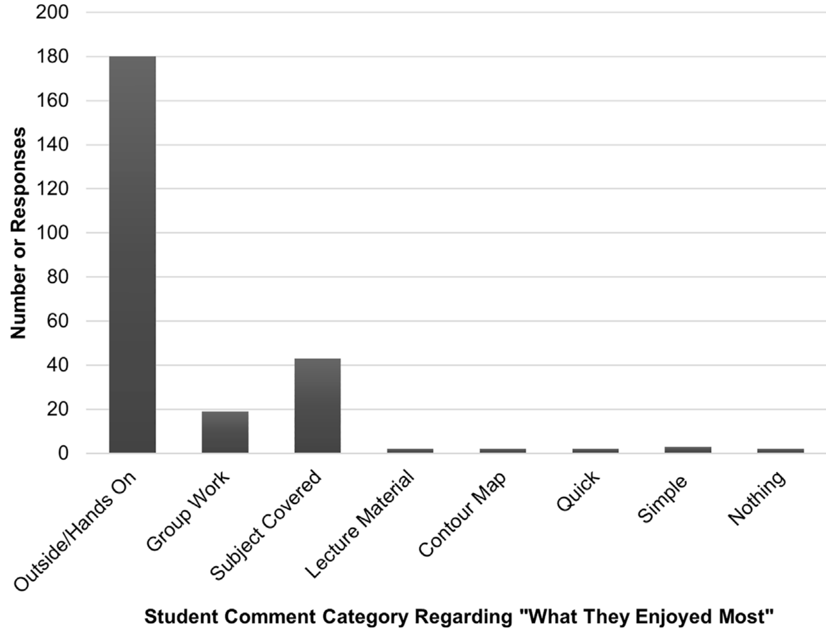

FIGURE 6 | Tally of students' answers to the question "What did you enjoy most about this lab?" Open-ended responses were placed into one of the 8 categories shown.

(i.e., where to draw first and next lines) vary situationally depending upon the data and students' individualized interpretations. The difficulty of instructing students is compounded in an online setting, where students may not have the same opportunity to check their maps one-on-one with an instructor or with other students during an in-person class, and must seek these opportunities themselves (i.e., *via* online office hours or email). Receiving instructor feedback early and often and working in small teams are known to improve student learning, particularly in STEM. Group discussions require students to integrate individual ideas into joint observations (Warfa, Nyachwaya, Roehrig 2018) and allow students who are more familiar with discipline-specific terms and concepts (such as contouring in earth science) to teach their peers (Airey and Linder 2009). A lack of structured working groups in the online delivery mode may help explain why 59% of online students recommended providing "more/better information" to complete the lab, despite having access to a sample recorded lecture, pre-lab documentation, and other additional resources. Although group discussions of field and mapping concepts are not easy to reproduce in an online delivery mode, online teaching strategies can be implemented to help (Kanetaki et al., 2021; Kanetaki et al. 2021a; Kanetaki et al. 2021; Kanetaki et al. 2021b; Kaup et al., 2020; Kreijns et al., 2004). For example, TAs of online sections could host synchronous sessions to facilitate group discussion and inquiry between students. However, synchronous sessions have the downside of placing additional burdens on students with family and work obligations, particularly in a pandemic. To address this, students could be allowed to sign up for time slots that best fit their schedules, or TAs could replicate the discussion experience asynchronously through online discussion boards. Teaching contouring in a more successful way may require additional resources to help students internalize the principles of the activity (rather than just follow a set example) and, where possible, be able to understand and "self-check" where their own work or the work of their peers may violate the principles of the contouring activity (Kanetaki et al., 2021; Krouska et al., 2021).

We also note opportunities to improve the in-person version of the activity. One challenge was how to allocate measurement equipment among student groups. Due to equipment limitations, students worked in groups of up to 10–15. Certain students tended to gravitate towards operating the meters, limiting participation by others. In the post-lab surveys, 7% of in-person students wanted smaller groups and said they were not able to work "hands-on" with the equipment. This was notable since the "hands-on" nature of the lab was by far the most well-liked aspect (**Figure 6**). Rotating group members through assigned roles (such as data recording, opening the wells, operating the beep tape, etc.) at each well could be a potential improvement for teaching this lab with larger classroom sizes and/or limited equipment. This could also facilitate better social distancing, which was difficult in both the SP21 and FA21 labs, by allowing smaller groups to visit more wells simultaneously. In future semesters, concomitant labs will be rotated through the groundwater lab over a 2-week period to increase the availability of physical space and equipment during the exercise and reduce the group size to 4-7 students.

In summary, this comparative study reveals that hands-on field experiences during the COVID pandemic had extensive benefits over online alternatives. Students in the hands-on activity performed better in the lab assessments, enjoyed being outdoors and expressed greater enthusiasm for taking water-related classes and pursuing water-related careers. In future semesters, we hope to reduce the gap in student learning outcomes between online and in-person participants by implementing simple changes to the online labs, such as adding a working session on contouring principles. It is possible that these changes will also positively impact online participants' affinities for water science by enhancing student-TA interactions, student confidence in the material, and feelings of being connected and belonging in the earth science learning community. Even with these improvements, online activity cannot simulate the quality of being outdoors, which was one of the favorite aspects of the exercise for in-person participants. We, therefore, emphasize the value of university investments in multi-use, accessible outdoor laboratory spaces within walking distance of classrooms. Establishing and maintaining these spaces requires support from faculty, administrators, landscape architects, and groundskeeping staff, but the reward is a measurable improvement in student learning experiences, particularly during a pandemic.

DATA AVAILABILITY STATEMENT

The educational materials generated for this study can be found in the CUAHSI HydroShare database: https://doi.org/10.4211/hs.7f6295a88f2743a58e3447db650df0d2

AUTHOR CONTRIBUTIONS

AS and JS conceived the study idea. ZC compiled the lab score dataset, analyzed statistics, and interpreted the results. KL prepared and distributed the FA21 affinity surveys, and BB and KL compiled, analyzed, and interpreted responses. All authors contributed to writing and editing.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.877327/full#supplementary-material

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