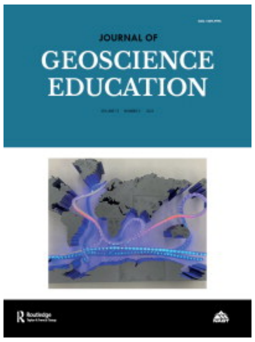

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A citizen science approach to teaching climate change in introductory-level undergraduate general science courses

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ABSTRACT
Hundreds of thousands of undergraduates enroll in general education science courses to fulfill university core requirements. However, many of these lecture-based courses fail to foster high-level data literacy skills. This work details the design, implementation, and analysis of a new climate change-based classroom activity for college students that pairs data interpretation with participation in an online citizen science project called Floating Forests (http://floatingforests.org). We pilot tested our activity in introductory geoscience and biology courses at six universities (~1,500 students) during the 2020–2021 academic year. Additionally, we developed and validated a survey to assess how engagement with our activity impacted students' self-reported changes across four factors: (1) perceptions of the impacts of climate change, (2) data literacy self-efficacy, (3) beliefs about the value of citizen science, and (4) beliefs about science engagement. In a pre- to post-test comparison, students who utilized our activity in their courses showed statistically significant increases ($p < 0.05$) across all four factors. These results highlight the potential benefit of implementing data-driven, citizen science-based activities in introductory-level undergraduate courses.

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Student beliefs; citizen science; data literacy; curriculum development; higher education

Purpose and learning goals

Nearly all institutions of higher education in the United States require students to enroll in an introductory science course to fulfill their institution's liberal arts requirement. Non-science majors enrolled in these introductory courses make up a large fraction of the student population more broadly. Unfortunately, many do not recognize the importance of science to their future careers (Glynn et al., 2007). Post-graduation, these students enter the workforce in a range of occupations in which they may not explicitly need deep content knowledge of any particular scientific discipline. Nevertheless, they can still benefit from having an enhanced scientific understanding, an ability to think critically, and ability to make evidence-based conclusions when presented with data (Lyons, 2011). For many of these undergraduate non-science majors, these courses will be their last formal exposure to science. Thus, a focus on epistemology in general education science courses will pave the way for a more scientifically and data literate society (National Research Council, 1996).

In this work, we applied a curriculum model developed by Simon et al. (2022) for astronomy education to create and evaluate a citizen science-based activity for undergraduate, introductory level geoscience and biology courses. This activity uses data and materials from the Floating Forests citizen science project (www.FloatingForests.org), and is hereafter referred to as the Floating Forests Activity. It takes a multi-faceted, data-driven approach to improve students' (1) perceptions of the impacts of climate change, (2) data literacy self-efficacy, (3) beliefs about the value of citizen science, and (4) beliefs about science engagement. We developed and validated a four-factor, Likert-scale survey to evaluate the impact of the activity across these aforementioned objectives. The remainder of this paper describes our curriculum and assessment design, details the results of our survey and analysis, and demonstrates the potential value of data-rich, citizen science-based classroom investigations more broadly.

Literature context

Data literacy is *"the ability to understand and use data effectively to inform decisions"* and means an individual can identify, collect, organize, summarize, and prioritize data (Koltay, 2015; Mandinach & Gummer, 2013, p. 30). Although improving undergraduate students' science literacy has been a priority of general education science courses for decades (National Research Council, 1996, 2009, 2010), the

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development and implementation of instructional materials aimed at improving students' proficiency with data continues to lag behind. Prior research has shown that undergraduate students struggle to distinguish between data and evidence (Lyons, 2011) and with making predictions, observations, or explanations when presented with real data (e.g., Kastens et al., 2009; Mattox et al., 2006; Tien et al., 2007). The COVID-19 pandemic further highlighted the need for the public to be able to reason critically when presented with data. These skills are often overlooked in general education science courses where the predominant style of lecturing prioritizes prescribed content (Gray et al., 2012). Because the traditional, lecture-based approach may remain the primary mode of instruction for many courses due to logistical constraints, we believe lectures must be supplemented with activities that enhance data literacy and promote critical thinking.

Wolff et al. (2016) present the construct of data literacy as a skill that can be sharpened with practice and experience. Furthermore, additional studies suggest that the inclusion of real-world data in the classroom is ideal for enhancing students' data literacy skills (Gould et al., 2014; Kjelvik & Schultheis, 2019). They also point out the importance of extending these real-world data experiences to large, complex data sets. As we enter the era of big data, integrating curriculum into the general education classroom that involves interaction with large datasets would provide non-science majors with skills that will serve them in the rest of their undergraduate tenures, in the workforce, and in their everyday lives.

Citizen science as a tool to bring big data to the college classroom

Inquiry-based learning is an effective pedagogical strategy for improving data literacy skills (Erwin, 2015; Vahey et al., 2012). With its strong focus on metacognition, students develop areas such as critical thinking, problem solving, and project management skills. Students develop these skills by working with actual data and real-world applications (Apedoe et al., 2006).

Despite the demonstrated effectiveness of inquiry-based learning, there is a major barrier to wider adoption: the burden often falls on instructors to identify appropriate data sets and scientific questions for investigation (Mueller et al., 2011). One solution is to use existing citizen science projects. These projects often have scientific questions with large datasets that are approachable to students. The incorporation of citizen science projects into the undergraduate, general education curriculum can engage students in analyzing and interpreting data, making observations, and making predictions with real data (Slater et al., 2008; Tien et al., 2007).

One form of citizen science involves crowdsourcing aspects of the data analysis process, enabling research teams to solve problems involving large quantities of data more efficiently while taking advantage of humans' innate ability to recognize patterns and detect anomalies in the data (e.g., Trouille et al., 2019 and the references therein). Studies across a variety of educational disciplines have seen significant gains in terms of student engagement and achievement with the inclusion of citizen science in their curricula (Coleman & Mitchell, 2014; Vitone et al., 2016). Students gain practical experience and learn to apply it directly, which also promotes critical thinking and problem solving in ways that traditional lectures cannot (Shah & Martinez, 2016).

Despite these aforementioned benefits, there remains relatively little work in the education research literature on the use of citizen science as the focal point of inquiry-based learning activities in undergraduate courses. In a survey of citizen science publications, classroom education was the primary focus of only 7% of papers published between 1997 and 2014 (Follett & Strezov, 2015). Most of these papers focused on citizen science projects that were conducted on school grounds directly (e.g. monitoring butterfly populations; Kelemen-Finan et al., 2013). Citizen science-based experiences for undergraduate, non-science majors have been conducted almost exclusively in biology (e.g., Hitchcock et al., 2021; Trautmann, 2013) and astronomy courses (e.g., Slater et al., 2008, 2011; Trouille et al., 2019). Considering the limited number of publications that highlight the use of citizen science in undergraduate classrooms, it is not surprising that there are even fewer published studies on the use of citizen science as a tool to improve students' data literacy in the undergraduate classroom.

Curriculum development model overview

The curriculum development model we used as the blueprint for our climate change-based activity is described in detail in Simon et al. (2022) and summarized below. The model was created with the goal of improving general education students' self-reported ability to interpret and analyze data representations (e.g., tables, graphs, and figures), while simultaneously introducing them to citizen science as a tool that would empower them to make meaningful contributions to science. With these goals in mind, the curriculum development model consists of three distinct parts:

1. A lecture-tutorial-based introductory activity that provides students with the opportunity to develop representational competence and essential background knowledge of the discipline.
2. A citizen science investigation that empowers learners to explore real data from the forefront of active research in Science, Technology, Engineering, and Mathematics (STEM) and allows them to make contributions to the science community.
3. A data analysis activity that encourages students to engage in critical reasoning, while guiding them to make evidence-based conclusions in pursuit of answers to contemporary scientific questions.

The curriculum model places a strong emphasis on real-world applications and is intended to elicit deep student engagement with scientific topics and data *via* the "variation approach to learning" (Linder & Fraser, 2006). This is accomplished by presenting a diverse set of data representations in tandem with a series of questions, tasks, and thought experiments (e.g., student debates) that are intended to link concepts and provide students with both increased representational competence, data literacy, and disciplinary discernment.

The first and third components of the curriculum model were developed to provide students with the proper context and support needed to understand the value of citizen science and students' ability to contribute. Typically, citizen science projects attract a population of free-choice learners who are already intrinsically motivated to contribute to scientific research (Raddick et al., 2013). Undergraduate students enrolled in a required introductory science course, however, may not have that same intrinsic motivation or general interest in the disciplinary topic the citizen science project highlights. As such, the lecture-tutorial component of the curriculum development model provides students with the opportunity to delve more deeply into the disciplinary topic emphasized in the citizen science project while the data analysis portion of the model uses data derived directly from the citizen science project to help students more readily discern the value of the project in the context of answering relevant scientific questions.

Student survey results from classroom testing of an astronomy-based activity developed utilizing this model suggest that the activity was effective at improving general education astronomy students' data literacy self-efficacy. Furthermore, students indicated improved positive beliefs surrounding their ability to make meaningful contributions to science *via* participation in citizen science. The astronomy-based activity was developed prior to the Floating Forests Activity, but both activities were deployed for classroom use during the same academic year. Data from the astronomy-based activity were analyzed first, and it was not until the success of the curriculum model was demonstrated in astronomy that we endeavored to determine if the results were comparable in a non-astronomy field, at different institutions of higher education, and with different students.

Overview of floating forests citizen science project

To fulfill Part 2 of the curriculum development model's required components, we built the climate change activity around the citizen science project Floating Forests (www.floatingforests.org). Floating Forests is an online citizen science project using the Zooniverse platform, a suite of sophisticated tools and infrastructure supporting over 80 active projects and 2.5 million participants worldwide (www.Zooniverse.org; Lintott et al., 2008). The objective of the Floating Forests project is to generate a time series of giant kelp *(Macrocystis pyrifera)* populations at a global scale. Giant kelp is a species of brown algae with a worldwide distribution and great value, both as an economic and an ecological resource (Bulleri & Chapman, 2010; Ghedini et al., 2013; Schiel & Foster, 2015). In addition to its importance, giant kelp is also threatened by human activities, hence the need for global mapping and monitoring efforts. Floating Forests utilizes consensus classifications to detect giant kelp in satellite images and produces data of comparable accuracy to expert classifications (Houskeeper et al., 2022). Floating Forests is an ideal candidate for formal undergraduate curriculum development because there is almost no barrier to entry for participants. It is free and platform agnostic—all that is required is a device with an internet connection. All necessary training and instruction is included in the experience, and participants are able to contact the research team through the project web page if they have additional questions.

In addition to its ease of use, Floating Forest's focus on climate change impacts makes it a strong candidate for classroom integration. Climate change is an ideal topic to integrate into science courses because it encompasses a range of scientific disciplines broadly including geoscience, ecology, biology, chemistry, and physics. Additionally, it is a very timely topic that is distinguished by an extensive public dialogue that is riddled with misinformation (Cook, 2019; Treen et al., 2020). Real-world applications are important for sparking student interest in science. For example, an initiative to incorporate climate change into an introductory level college level geology course improved student learning outcomes and was overall positively received by the students (McNeal et al., 2014).

Study population and setting

Students enrolled in general education geoscience and biology courses at six institutions of higher education utilized the Floating Forests Activity during the 2020 - 2021 academic year (Table 1). Two institutions were located in the Western United States, two in the Midwest, one in the South and one in the Northeast. The students enrolled in these general education science courses were typically in the first two years of their undergraduate degree program. Depending on the institution type, these courses enroll 20 - 200 students. All courses had a full-time faculty member as the instructor of record, and several of the courses also included 1-10 graduate-level teaching assistants. 52.5% of students in the data set identified as female, 44.5% identified as male, and 3% either declined to indicate their gender preference

Table 1. Institution types, numbers of student participants, and course subjects. Institution names redacted for anonymity. "No Attribution" refers to students who did not report an identifiable institution affiliation.

Institution	Institution type	Participant *N*	Course subject
Institution 1	Public University, Very High Research Activity (R1)	222	Geoscience
Institution 2	Public Community College	34	Biology
Institution 3	Public University, High Research Activity (R2)	415	Biology
Institution 4	Public University, Very High Research Activity (R1)	135	Geoscience
Institution 5	Public University, Very High Research Activity (R1)	530	Geoscience
Institution 6	Private Liberal Arts College, Historically Black College or University (HBCU)	48	Geoscience
No Attribution		21	
Total		1405	

or self-described. 59% of students identified as White, 11% identified as Black, 15% identified as Asian, and 7% declined to answer or preferred to self-describe. Additionally, 14% of students identified as Hispanic/Latino. Note that these groups do not necessarily add up to 100%, as students were allowed to select multiple options. To conduct research with human subjects, the research team gained approval from the institutional review board (IRB) of all universities where data were analyzed.

Materials and implementation

Activity implementation

The Floating Forests Activity was designed to take one 75-90 min class or lab period to complete. Due to the COVID-19 pandemic, the participating courses implemented the activity either synchronously online *via* Zoom or in a fully asynchronous online course format with students working individually. Instructors were not required to provide substantive background information prior to administration of the activity as it was intended to serve as an introduction to the topic of climate change. Instructors were asked to provide students with a brief introduction to crowdsourcing, assuring students that any potential errors in classification on their part would have little impact on the data quality. Following this brief introduction, students were given access to the Floating Forests Activity and worked through it at their own pace.

Curriculum in context: How the model informed our content

The curriculum development model we utilized (described above) had three parts, corresponding to the three parts of the Floating Forests Activity. The complete activity can be found in the supplemental materials or at www.classrooms.zooniverse.org.

The first component of the curriculum development model leveraged an active learning technique to improve students' representational competence while building relevant disciplinary knowledge. Accordingly, Part 1 of the Floating Forests Activity utilized a lecture-tutorial approach to establish baseline climate change content knowledge that is foundational to the rest of the activity. Lecture-tutorials are activities that pair carefully sequenced tasks with corresponding representations to help students build the mental models required to overcome common conceptual misconceptions (Prather et al., 2004). Lecture-tutorials have been used in many introductory science courses, including geoscience and astronomy, with much success (e.g., Kortz et al., 2008; Prather et al., 2009). The lecture-tutorial section of the Floating Forests Activity covered greenhouse gases and the carbon cycle, with a strong emphasis on interpreting graphs and historical data. For example, we presented long term records of atmospheric carbon dioxide at a scale that illustrates both annual cycles as well as long term trends. Students were tasked with interpreting the data at both scales so that the difference between the "natural" carbon cycle and the effects of direct anthropogenic input can be compared.

The relevancy of scale is reiterated in Part 1 of the Floating Forests Activity in the context of the magnitude of climate change impacts. Students were introduced to the concept of statistical modeling with a qualitative example in which the modeled impacts of natural and anthropogenic drivers of climate change are visually compared. The activity presented data and model outputs from Haustein et al.'s (2017) report. This report clearly showed a sharp increase in the impacts of anthropogenic activities as compared with natural factors over time, which provided a strong case study in which the importance of scales and rates were discussed. Upon completion of this section, students summarize the links between human activity, atmospheric carbon dioxide, and global temperature. Furthermore, they understand the importance of temporal scale and rate in the context of climate change.

The second component of the curriculum model emphasized the importance of giving students an opportunity to explore real data while directly contributing to research. Part 2 of our activity leveraged the Floating Forests online citizen science project (described in the previous section) as an authentic research experience in an inquiry-based investigation of a real-world scientific issue.

We created a separate practice version of Floating Forests exclusively for this activity. This consists of 15 curated satellite images which were selected because they provide exemplary representation of the most common phenomena present in the actual Floating Forests dataset. Specifically, they include several good examples of kelp, as well as some examples of confounding features such as benthic mudflats, clouds, waves, image noise, and various other artifacts. Students thoroughly study these images in order to develop confidence in their ability to identify kelp before visiting the primary Floating Forests project website and contributing to the active project. At this point in the activity, students are working with actual data and making real contributions to the project. While this portion of the activity is primarily intended for open-ended inquiry, the activity provides a framework for students to reflect on their experience, as well as resources for addressing any lingering questions they may have. Upon completion of this section, students gain confidence classifying images on Floating Forests. Specifically, they should be able to differentiate between kelp, waves, clouds, and mudflats, and should develop a better understanding that authentic data is rarely (if ever) clean.

The final component of the curriculum model concerns the importance of data-informed activities that guide students toward making evidence-based conclusions. To this end, Part 3 of the Floating Forests Activity tied the climate change concepts introduced in Part 1 together with kelp forest ecology introduced in Part 2 as a more structured inquiry-based experience. Students were presented with data representations such as seasonal maps of kelp forests generated *via* citizen science classifications on Floating Forests (Figure 1), graphs of kelp population trajectories, and temperature data (both regional and global in scale) and then

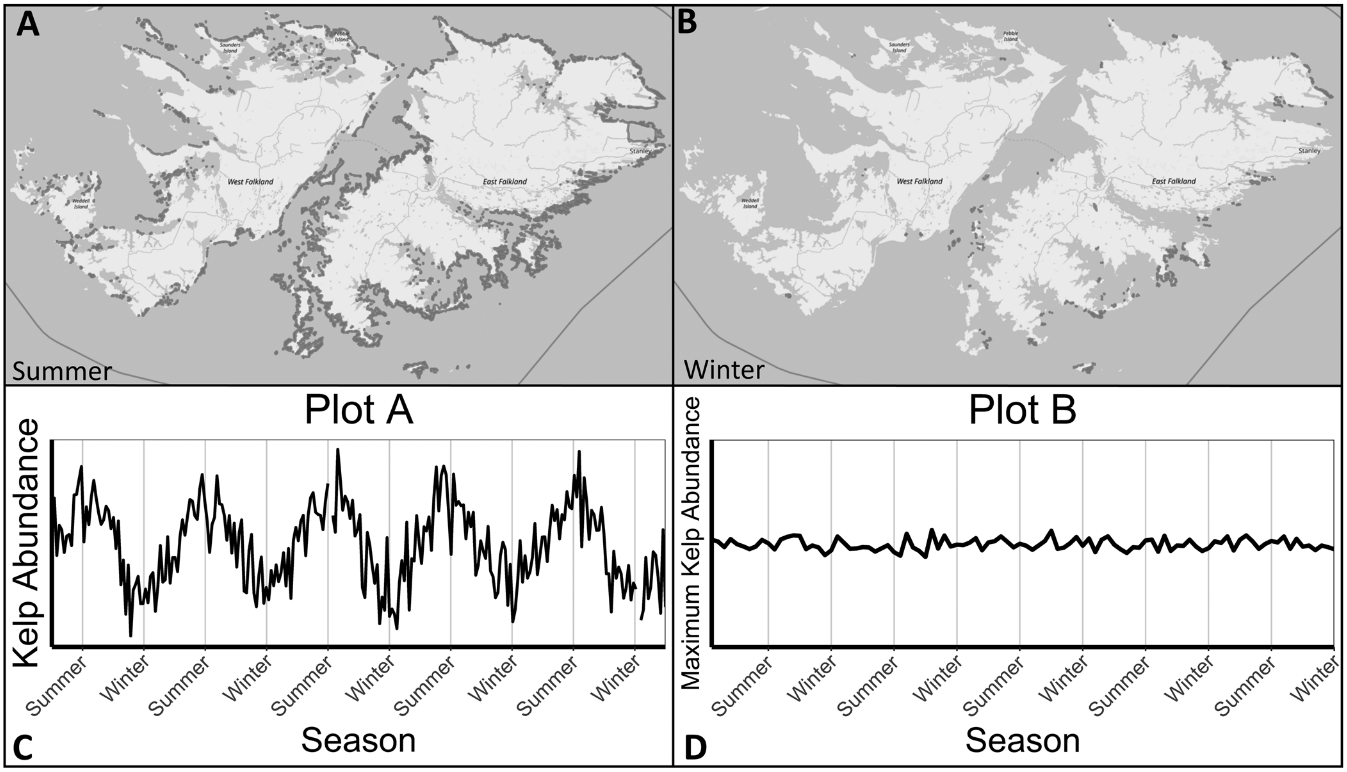

Figure 1. Representation used in part 3 of the activity. Students are provided with an interactive map that allows kelp coverage to be toggled on and off by season. Panels A and B display summer and winter kelp coverage, generated by citizen scientists and the Floating Forests project. Students are tasked with interpreting seasonal dynamics and selecting the plot (options found in panels C and D) which best represents the observed patterns.

tasked with interpreting the patterns and trends across these representations. This consideration of both seasonal and long-term trends reinforces the concepts introduced in Part 1 by presenting them in an ecological context. Part 3 concluded with a thought experiment regarding climate change "hot spots" and how ecological lessons learned in a rapidly changing region such as Tasmania can be generalized to create predictions about future changes in other places. Upon completion of this section, students should be able to synthesize data from multiple sources and relate it to their growing knowledge of the global climate system in order to make evidence-based conclusions about the potential future ecological effects of climate change.

As mentioned previously, student survey results from classroom testing of an astronomy-based activity utilizing the same curriculum model were promising (Simon et al., 2022). As such, our evaluation of the Floating Forests Activity placed specific emphasis on demonstrating the efficacy of the aforementioned curriculum model across disciplines, to see if its application to an activity that includes geoscience and biology topics would reproduce analogous student self-efficacy improvements to those observed in astronomy.

Evaluation

Survey design

Our assessment of the Floating Forests Activity was designed to measure students' self-reported change across four different learning objectives: climate change perception (students' perception of the drivers and impacts of climate change), data literacy self-efficacy (students' self-reported proficiency using data/representations to make evidence-based conclusions), value of citizen science (students' beliefs about the value of citizen science to the scientific community), and science engagement (students' beliefs about contributing to and engaging with science in a meaningful way). The final survey consisted of 21 Likert-style items loosely inspired by Estrada et al. (2011), and more closely based upon the survey utilized in Simon et al. (2022). Each of the survey items were rated on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree). Of the 21 overall items, 14 were included on both the pre and post-tests. In addition to these core items, the pretest included three baseline items regarding students' general beliefs about science, and the post-test included four items in which students more directly reflected on the activity's impacts. A complete list of survey items is included in Supplemental Material 1.

Data collection

Our survey was administered online *via* Qualtrics (https://www.qualtrics.com). The survey was administered in a pre/post-test fashion in both the Fall of 2020 and Spring of 2021, with students taking the pretest as an at-home assignment in the first week of their course, and the post-test within one week of the activity's completion. The timing of activity and evaluation administration was not standardized between institutions, as each instructor incorporated it into their syllabus independently. Per IRB protocol, instructors informed their students that their course had been selected to participate in a research study that involved two surveys and an activity. Students were notified that if they chose not to participate, there would be no penalty.

Data cleaning and data analysis

Raw student survey data was initially cleaned by removing all incomplete responses, as well as all responses that were completed in under 30 s, as we were concerned that these were low-effort responses and would yield poor quality data. In the case of duplicate responses (likely caused by unintentional resubmissions), students' most recently completed response was retained. Students' pre- and post-test responses were matched using unique, confidential identifiers. The final number of student survey responses after data cleaning and matching is shown in Table 2. We attribute the high level of attrition to a combination of factors including students dropping the course after completing the pretest, students not attending class on the day the Floating Forests Activity was implemented, lack of academic incentive for students to complete surveys (e.g. little to no impact on students' course grade), and the added stress of the COVID-19 pandemic. In addition, some students incorrectly entered their anonymous identifiers, leading to completed post-tests that could not be matched with a corresponding pretest.

We used the matched dataset for the remainder of our data analysis because it is the only subset of our data where we could guarantee that students completed the pretest, Floating Forests Activity, and the post-test. Before proceeding, however, we compared the matched and unmatched datasets using an unpaired Wilcoxon Ranked Sum test. This nonparametric test was selected given the ordinal, non-normal nature of the dataset and was performed to ensure that the subset of matched responses were representative of the larger unmatched dataset, which would enable the implementation of paired analyses on the matched dataset. Each respondent's individual item responses were averaged to create an overall respondent score for the pre and post-test separately. We then compared the overall score for respondents with and without matches for the pretests and found no significant difference ($\text{Mean}_{\text{matched}}$ = 5.90, $\text{Mean}_{\text{unmatched}}$ = 5.99, $\text{N}_{\text{matched}}$ = 388, $\text{N}_{\text{unmatched}}$ = 875, $Z=-1.56$, $p=0.12$). We repeated the process on the post-test responses, again finding no significant difference between the matched and unmatched datasets ($\text{Mean}_{\text{matched}}$ = 6.24, $\text{Mean}_{\text{unmatched}}$ = 6.18, $\text{N}_{\text{matched}}$ = 388, $\text{N}_{\text{unmatched}}$ = 142, $Z=-1.41$, $p=0.16$). These results allowed us to implement pairwise analyses on the matched dataset exclusively.

To assess potential change between students' pre- and post-test responses, we calculated the average of each student's pre and post-test responses and performed a Wilcoxon Signed Rank test. Individual item response averages were compared for each of the four learning objectives, as well as an overall average of all items on both the pre- and post-tests. Wilcoxon effect sizes were calculated using the formula $r=Z/\sqrt{\text{N}}$, where Z is the standardized test statistic and N is the number of response pairs. The threshold for statistical significance in these analyses was set at 95% confidence ($\alpha=0.05$).

Table 2. Self-efficacy survey student response rate after cleaning the data.

Administration	Number of students (*N*)	Percentage of total (N/N Total)
Pretest	1263	89.9
Post-test	530	37.7
Matched pairs	388	27.6

Reliability & validity

In order to interpret our survey results at the category level, survey items were grouped into the four learning objectives, hereafter referred to as factors: climate change perception, data literacy self-efficacy, value of citizen science, and science engagement. We assessed the validity of these factors with both an exploratory factor analysis (EFA) and a confirmatory factor analysis (CFA). We used the following indices and thresholds to assess the degree of model fit: RMSEA ≤ 0.06, SRMR ≤ 0.08, CFI ≥ 0.95, and TLI ≥ 0.95 (Brown, 2015; Hu & Bentler, 1999).

The matched pre- and post-test dataset ($N=388$) was randomly split in half to create separate data sets to perform exploratory and confirmatory factor analyses for instrument validation, leaving 194 responses for each test. The EFA indicated that a 4-factor model was appropriate, and CFA testing of this 4-factor model showed acceptable fit (RMSEA =0.047, SRMR = 0.063, CFI =0.97, and TLI =0.95). For more details regarding these analyses, refer to Supplementary Material 2. Given the adequate fit of this 4-factor CFA, items were grouped by factor for the remaining statistical analyses.

We used Cronbach's alpha to assess internal reliability, with a critical threshold of 0.7 (Cronbach, 1951; Hair et al., 2019). Each factor met this threshold for alpha, indicating adequate reliability (climate change perception = 0.91, data literacy self-efficacy = 0.81, value of citizen science = 0.85, science engagement = 0.82).

Results

We first quantified the change in students' total survey scores (i.e., the sum of all four factor scores) as a measure of overall change to better understand the impact of the Floating Forests Activity more generally. The mean of the 14 items that appeared on both the pre- and post-tests was calculated at the individual student level to generate overall test scores. These pre and post-test means were compared using a Wilcoxon Signed Rank test. We found a statistically significant difference between the pre- and post-test overall scores in the matched data, indicating that the Floating Forests Activity broadly increased students' beliefs across our four learning objectives (Mean_{pre}= 5.99, $\text{Mean}_{\text{post}}$ = 6.23, $Z=-8.21$, $p<0.01$, $r=0.23$).

To quantify the impact the Floating Forests Activity had on each of the factors more specifically, we performed an identical analysis of students' pre and post-test scores on each factor individually. The results of this analysis are found in Table 3 and Figure 2.

Perception of climate change impacts

Student responses to the "Perception of Climate Change Impacts" factor showed a small but significant increase

Table 3. Results from factor-level Wilcoxon signed-rank tests using the matched pairs data ($N = 388$).

Factor/Category	Item Numbers	Pretest Mean ± SD	Post-test Mean ± SD	*z*-score	*p*-value	Effect Size
Climate Change Perception	4–10	6.18 ± 1.04	6.40 ± 0.87	−8.95	<0.01	0.18 (small)
Data Literacy	11–13	5.96 ± 0.93	6.16 ± 0.86	−6.27	<0.01	0.14 (small)
Value of Citizen Science	14, 15	5.74 ± 0.88	6.07 ± 0.88	−7.74	<0.01	0.22 (small)
Contribution Capacity	16, 17	5.57 ± 1.21	5.91 ± 1.07	−6.99	<0.01	0.17 (small)

Pre- and post-test means and standard deviation (SD), *z*-scores, statistical significance ($p < 0.05$), and Wilcoxon effect sizes are reported for the four learning factors. The mean and standard deviations were on a scale from 1 (strongly disagree) to 7 (strongly agree).

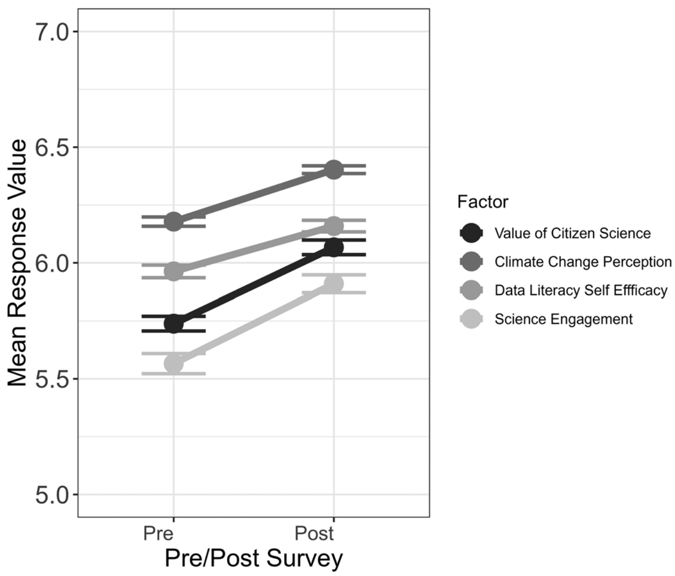

Figure 2. Comparison of matched pre- and post-test factor scores ($N = 388$). Factor scores are the average score of all items within a factor, on a scale from 1 (Strongly Disagree) to 7 (Strongly Agree). Each factor corresponds to one of the Floating Forest Activity learning goals.

(i.e., higher levels of agreement that climate change is a serious issue after completion of the activity) ($Mean_{pre}$= 6.18, $Mean_{post}$ = 6.48, $Z = -8.95$, $p < 0.01$, $r = 0.18$). Several of our survey items can be treated as content knowledge indicators. For example, our item "*Small changes in Earth's average temperature over time seriously impact the environment*" is an objectively true statement, and it was a key concept emphasized in the Floating Forests Activity. Student responses to this item showed overall increases in agreement, which indicates that to some degree this information was internalized. Student responses shifted from an average of 6.21 in the pretest to 6.53 in the post-test ($Z = -5.08$, $p < 0.01$, $r = 0.18$).

Another important concept covered by the activity is the degree to which human activity has contributed to climate change. Students were presented with the visual output from a statistical model that compared the importance of anthropogenic and natural drivers of climate change, which showed that anthropogenic factors are substantially more important than natural ones. In order to determine the efficacy of this approach, we asked students two separate survey items:

1. Human activities play the most significant role in contributing to climate change.
2. Human activities play a significant role in contributing to climate change.

We saw no significant difference between pre and post-test scores for the second item, likely due to a high pretest average of 6.5 indicating that students were already aware that humans are a major driver of climate change. However, the first item's post-test scores were significantly higher than pretest scores ($Mean_{pre}$ = 6.08, $Mean_{post}$ = 6.38, $Z = -3.63$, $p < 0.01$, $r = 0.14$). This indicates that students showed positive change in their understanding of the degree to which human activities drive climate change, that is more students understood that anthropogenic activities are *the most* significant driver of climate change. Had our activity failed to communicate this information, we would expect student responses to be more similar across these items, indicating that they did not internalize the difference between these statements.

Data literacy self-efficacy

One of the primary goals of the Floating Forests Activity was to improve students' beliefs about their data literacy skills, and we saw significant improvement at the factor level ($Mean_{pre}$= 5.96, $Mean_{post}$ = 6.16, $Z = -6.27$, $p < 0.01$, $r = 0.14$). One survey item within our data literacy factor was specifically intended to evaluate success in this area: *I am confident in my ability to interpret representations of data (graphs, tables, and charts) when seeking out answers to questions.* This item showed significant improvement from pre- to post-test results and had the highest effect size of any item in the data literacy factor ($Mean_{pre}$= 5.77, $Mean_{post}$ = 6.10, $Z = -4.78$, $p < 0.01$, $r = 0.16$). This suggests that our activity improves student self-efficacy specifically in interpreting data.

Beliefs about the value of citizen science and science engagement

Both the "Value of Citizen Science" ($Mean_{pre}$= 5.74, $Mean_{post}$ = 6.07, $Z = -7.74$, $p < 0.01$, $r = 0.22$) and the "Science Engagement" ($Mean_{pre}$= 5.57, $Mean_{post}$ = 5.91, $Z = -6.99$, $p < 0.01$, $r = 0.17$) factors showed significant positive changes in student response scores between the pretests to post-tests (Table 3, Figure 2). These results indicate that participation in the Floating Forests Activity leads to an increase in positive student beliefs about the value of citizen science and about engagement with science more generally.

Post-Test items

Our survey included four additional post-test items that specifically targeted students' attitudes toward citizen science and the data literacy components of the Floating Forests Activity. Although a full mechanistic investigation of how citizen science inclusion may impact student learning was beyond the scope of our evaluation, we did ask students to quantify their interest in further contributing to citizen science projects. Eighty percent of students responded that they would be interested in continuing to contribute to the Floating Forests project, with slightly more (83%) indicating that they were interested in generally participating in other citizen science projects (Figure 3, panels C and D). Additionally, 85% of students indicated that they would be receptive to further citizen science-based course curricula (Figure 3, panel A).

Furthermore, we asked students if the Floating Forests Activity improved their data literacy skills, with an overwhelming 94% responding positively (Figure 3, panel B). This cluster of post-test only follow-up items further supported the notion that overall, participation in the Floating Forests Activity may lead to direct improvements in students' self-reported data literacy skills, as well as increased interest in participation in citizen science (i.e., authentic scientific research).

Interpretations

In this work, we present the development and testing of an inquiry-based, citizen science activity on the topic of climate change for non-STEM majors. We also evaluated the efficacy of the activity as it relates to our 4 factors: climate change perception, data literacy self-efficacy, value of citizen science, and science engagement. This evaluation was carried out *via* a Likert style pre/post survey, and nonparametric analysis of the responses indicated significant positive change across all four factors. Students were more aware of the importance of climate change, reported higher levels of confidence in their data-literacy skills, were more positive about their ability to contribute to science, and reported increased belief in the value of citizen science after completion of the Floating Forests Activity in their undergraduate course. In addition, post-test-only data indicated that students enjoyed the activity and were interested in making further contributions to citizen science projects.

These results were generally consistent with those reported in Simon et al. (2022) for an astronomy activity developed using the same curriculum model described previously. In both this study and the Simon et al. study, there were

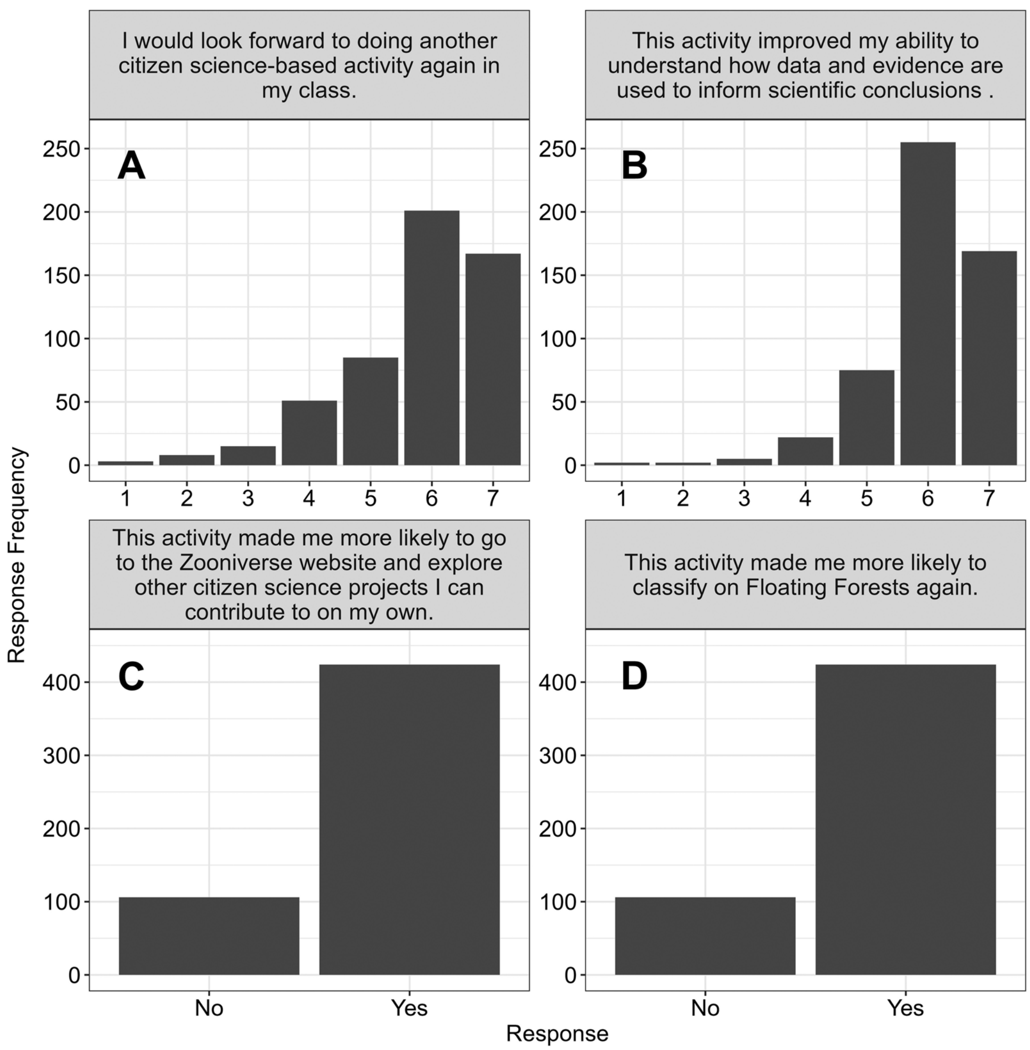

Figure 3. Bar chart of matched student responses ($N = 388$) to the four post-test-only items. The x-axis of panels A and B can be interpreted as 1 = Strongly Disagree, 2 = Disagree, 3 = Somewhat Disagree, 4 = Neither Agree nor Disagree, 5 = Somewhat Agree, 6 = Agree, 7 = Strongly Agree.

statistically significant increases across the three factors consistent between both studies: data literacy self-efficacy, students' beliefs about the value of citizen science, and beliefs about science engagement. Another consistency between both this study and the Simon et al. study was the inflated pretest scores for nearly every item on the assessment. These inflated pretest scores likely created a ceiling effect which contributed to generally low effect-sizes, which was also unsurprising due to the large scale nature of the beliefs in question as well as the brevity of our activity in the context of the overall course. Although the effect sizes were low, the statistically significant increases for each of the factors both in this study and the Simon et al. suggest that both the Floating Forests Activity and the astronomy activity were successful at improving students' beliefs and perceptions across a variety of factors, rather than leaving students with feelings of inadequacy post-activity (James et al., 2022).

There was little negative feedback provided by students in terms of potential improvements to be made to the Floating Forests Activity based on survey responses. Most notably, student respondents noted that several of the activity's questions were worded too vaguely. We addressed these concerns between the first and second semester of data collection by rephrasing these questions to be more focused, and in some cases added additional supporting materials. For example, the first iteration of the first part of the activity asked students to "explain short term changes in atmospheric CO_2 over time". Several students felt that "short term changes" was too vague, and we updated this question to specify "the seasonal pattern we observe in atmospheric CO_2 over the course of one year". This question was paired with a figure that depicts atmospheric CO_2 concentrations over time, and to further clarify the intention of the question, we added an inset that highlighted change on an annual, seasonal scale.

Limitations

COVID-19

One limitation of this study was the timing of the COVID-19 pandemic. At the inception of the activity's development, it was intended for collaborative use in in-person classes. As the pandemic developed and most academic institutions moved to online formats, we adapted the curriculum to prioritize flexibility by making it available *via* Google Docs to allow instructors to easily implement the activity. While this flexibility was critical given the rapid and often chaotic shift to virtual learning, it also meant that we had no way to standardize implementation between instructors. While all pilot instructors administered the activity virtually, two out of the ten pilot instructors reported administering the activity asynchronously.

In addition, this reduced capacity to standardize implementation affected the timing of pre- and post-test administration. Ideally, students would have completed the pre- and post-tests immediately before and after completing the activity, but this was simply not possible for many instructors to accommodate. Therefore, it is likely that differences in pre- and post-test responses were influenced by both the Floating Forests Activity as well as by students' other learning experiences in their courses. To help account for this, we included an item on the post-test that directly asked students if participation in the Floating Forests Activity improved their data literacy self-efficacy, to which 94% of students reported that it did (Figure 3, panel B). While obviously not as conclusive as more tightly coordinated pre-/post-test administration, this direct self-reflection lends credence to our activity specifically impacting students' data literacy self-efficacy. The other three factors (climate change perception, beliefs about the value of citizen science, and beliefs about science engagement,) were more specific to our particular activity, and unless students were exposed to the topic of climate change or engaged in other citizen science-based classroom experiences concurrently, we can attribute at least a majority of the observed positive changes in students' beliefs to our activity.

Self-reported data

One limitation of our evaluation is that we relied on self-reported student data to assess the impact of the Floating Forests Activity. Self-reported data has been shown to poorly reflect objectively measured knowledge gains in college students (Bowman, 2010; Pike, 1999; Price & Randall, 2008). However, we developed our activity with a focus on general beliefs rather than specific content knowledge. While not directly equivalent to objective knowledge gains, perceived developmental changes are linked to student satisfaction, enthusiasm, and general attitudes toward science (Gray & DiLoreto, 2016; Pike, 1993; Terenzini et al., 1982).

As we continue to develop and evaluate curricula with an emphasis on data analysis, it is imperative that we work to evaluate changes in data literacy directly (rather than *via* self-reported measures alone). This serves as motivation to create and validate an appropriate instrument with which to assess data literacy directly (e.g., *via* a task-based assessment), which would provide an additional layer of quantitative evaluation of student learning to supplement the self-reported data used in this study.

Implications

Despite the aforementioned limitations, the results of our study indicate the curriculum model developed in Simon et al. (2022) for astronomy is effective in other disciplinary contexts (i.e., geoscience and biology). This has several implications that may be helpful to those interested in developing or implementing similar activities.

Specifically, we have shown that the Floating Forests Activity is suitable for use in undergraduate general science courses. It can be used as a standalone introduction to climate change with no necessary prerequisites and can measurably affect student understanding of climate change drivers and impacts. The Floating Forests Activity can be effectively implemented as an in-class assignment that students complete either independently or in small groups, or it can be completed outside the classroom (or in online class) as a take home activity or homework assignment. If inclined, instructors could adapt the Floating Forests Activity for in-class implementation by using the figures presented in the activity in lecture slides, and the accompanying questions and student debates to facilitate small group or entire class discussions (depending on class size). Although the Floating Forests Activity contains three distinct parts intended to flow together, each part could be used independently if an instructor prefers breaking the activity into shorter components between lecture segments.

The success of the Floating Forests Activity furthers the assertions made in Simon et al. (2022) that citizen science is an invaluable tool for bringing big data to undergraduate, general education, science courses in an accessible way. Inquiry-based, data-forward instructional activities centered around an active citizen science investigation can successfully improve students' self-reported data literacy skills. One key aspect of the Floating Forests Activity is that students did not simply participate in the Floating Forests Zooniverse project, but that they also interacted with project data that was generated by the contributions of other volunteers in the form of maps and graphs. This experience allowed students to hone their data literacy skills and improve their self-confidence, improving their ability to understand the value of scientific research as a result. Additionally, the activity addressed the motivations for the Floating Forests project's structure, the importance of the participants' roles as contributors, and how project data are generated, analyzed, and interpreted. This allowed participants to develop their epistemic understanding of scientific research.

Students often report that their classroom experiences with science lack relevance to their lives, and this work affirms that positive exposure to citizen science is a strong way to shift this perspective (Jenkins, 2011; Mitchell et al., 2017; Ruiz-Mallén et al., 2016). The curriculum model developed by Simon et al. (2022) and implemented here can be used as a blueprint for the development of classroom activities across a myriad of disciplines. This is an exciting prospect, as there are currently over 80 citizen science projects across ten disciplines active on the Zooniverse platform alone.

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