

ARTICLE

Eco-Education

Online citizen science in higher education courses

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Abstract

Climate change and biodiversity loss require us to engage the next generation of scientists in addressing global ecological issues. Introducing undergraduate students to citizen science allows them to learn scientific processes and content while contributing to real-world applications. We conducted a systematic review of literature to (1) identify what types of undergraduate courses and institutions use citizen science, (2) list the projects and platforms that have been implemented in online courses in undergraduate education, (3) examine how students participated in the projects through online courses, and (4) summarize learning objectives and reported benefits of student participation. In all, 44 studies about the use of citizen science in undergraduate online courses were found in 25 papers in the published literature. The most common projects consisted of classification of species or natural history (e.g., iNaturalist), which could be done mainly online but with data collection completed at a location available to the student. Citizen science projects were incorporated into multiple course formats (e.g., lecture, lab) and class sizes, and students were most frequently asked to collect and submit data. The most frequently reported learning outcomes included increased student interest/engagement, improved appreciation for the relevance of science to the “real world,” and practice using the scientific process, but rigorous assessment data were lacking in papers. The use of citizen science in online courses and institutions appears to be increasing, and we encourage faculty using these approaches with students to publish on their efforts, providing details about their implementation, assessment, and course context.

KEYWORDS

biodiversity, ecology, environmental monitoring, learning outcomes, participatory science, post-secondary, undergraduate

INTRODUCTION

The complexity of ecosystems creates a multitude of opportunities for scientific discovery through citizen

science projects. Broadly defined, citizen science includes volunteers who collect data for research or monitoring projects (Cardamone & Lobel, 2016). Citizen science is an effective tool to not only engage the public in science but

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also collect ecological data on a broad scale in the long term (Dickinson et al., 2010). Citizen science covers a range of topics, but monitoring of biodiversity in the face of global change has become the focus of many of these programs, including projects such as iNaturalist or eBird (Dickinson et al., 2010; Golumbic, 2024; Hitchcock, Sullivan, & O'Donnell, 2021). Changes in species' ranges, phenology, and behavior may also be tracked through citizen science projects (Di Cecco et al., 2021; Dickinson et al., 2010; Mesaglio & Callaghan, 2021; Tsujimoto et al., 2019).

To tackle climate change and biodiversity loss, we need to engage the next generation of citizens and scientists in these global ecological issues. Citizen science is an entry-level mechanism for this type of engagement (Dickinson et al., 2010; Johns et al., 2021; Smith et al., 2021). Introducing undergraduate students to citizen science helps to forge connections with real-world science and increases data literacy (Aivelo & Huovlin, 2020; Cardamone & Lobel, 2016; Heigl & Zaller, 2014; Hitchcock, Sullivan, & O'Donnell, 2021). It also provides opportunities for historically marginalized groups to be exposed to careers in STEM (science, technology, engineering, and mathematics) fields and research (Johns et al., 2021). In a case study with a mixed-methods design, students who participated in citizen science projects even reported having a stronger sense of belonging in science, an important aspect of retaining students in the sciences (Johns et al., 2021).

Motivation to tackle environmental challenges is impacted not only by engagement with science but also by the level of attachment to natural places (Haywood, 2014). For example, Haywood et al. (2016) used data from volunteers to create a model showing how place-based, citizen science can lead to individual and collective environmental action. They found a strong link between one's scientific study of a location and their sense of ownership or stewardship toward it. This affective change was accompanied by cognitive changes as volunteers felt they increased their knowledge and confidence through hands-on experiences (Haywood et al., 2016). Newman et al. (2017) also found that environmental decision making could be strengthened by leveraging the place-based characteristics of citizen science. Involving undergraduates in citizen science projects that connect them to a particular place may similarly increase their sense of stewardship and support for evidence-based decision making about environmental issues.

Although there are documented benefits to implementing citizen science projects in the undergraduate classroom, most studies are qualitative and limited in sample size (Aivelo & Huovlin, 2020; Caruso et al., 2016; Johns et al., 2021; Smith et al., 2021). Formal assessment

of the effects of student participation in these projects is lacking, particularly when it comes to evaluating the goals of enhancing data literacy (Bedell & Gates, 2021) or retaining students in scientific careers. Papers have also expressed challenges in separating the outcomes of the citizen science project from the outcomes of the overall course (Vitone et al., 2016). Finally, there is a lack of studies comparing the effectiveness of online versus in-person modalities (Aristeidou & Herodotou, 2020).

While online course modalities were already increasing in academia, the COVID-19 pandemic in 2020 and the subsequent lockdown of most educational institutions required faculty to make an almost overnight switch to online formats of instruction (Neuwirth et al., 2021). This created the need for the rapid development of laboratories and activities that would allow students to continue to interact with scientific principles and the environment but potentially hundreds of miles from the instructor (Gamage et al., 2020; Morrison et al., 2021; Radhamani et al., 2021). Online citizen science projects helped to fulfill this need as the infrastructure and methods for many projects were already in place and could be quickly adapted to online teaching (Dunbar-Wallis et al., 2024). Beyond the pandemic, flexibility in the learning environment has remained in the forefront of undergraduate education as students want to be able to work around other life commitments (Hews et al., 2022).

Online citizen science projects provide this advantage of flexibility in the learning environment. Non-traditional/non-residential students have an opportunity to be engaged in the scientific process without the restriction of in-person laboratory or lecture times (Race et al., 2021). Citizen science projects also allow students to connect to the ecology of a distant location (e.g., by scoring videos of nesting birds from another state through the project Woodpecker Cavity Cam) or their own backyard (e.g., using iNaturalist) and to discover that science does not just happen in academic spaces (Aivelo & Huovlin, 2020; Roche et al., 2020). These projects can promote a student's connection to a place and all the benefits of place-based learning (e.g., enhanced environmental stewardship), even though the course itself is online.

Technological advances in online platforms and smartphone applications have increased the ease of reporting information online, making the technological threshold lower for students to participate in citizen science (Bedell & Gates, 2021). Most projects require little to no additional costs for participation (Cardamone & Lobel, 2016). One of the most fundamental challenges with access to technology is the availability of reliable internet service (Pennino et al., 2022; Turnbull et al., 2021; Walsh et al., 2021), but this challenge has largely been overcome

by citizen science project applications that allow users to enter data and store it to be uploaded once they are in range of wireless service again. Privacy concerns that arise from the use of technology can also be mitigated by having students use a shared account created specifically for the class or use pseudonyms. Extensive training materials created by many projects also alleviate many technological concerns. Tab. S2 in Hitchcock, Sullivan, and O'Donnell (2021) has a range of ideas for how to deal with a variety of technological issues related to student use of iNaturalist that would also apply to other citizen science projects.

Citizen science projects are also adaptable to many disciplines and may achieve different learning objectives for the course. Objectives related to science literacy, data literacy, and the scientific method process are common reasons for adding citizen science to undergraduate curricula (Bonney et al., 2009; Heigl & Zaller, 2014; Hitchcock, Sullivan, & O'Donnell, 2021). Involvement in projects also builds “soft skills,” like collaboration and curiosity (Hitchcock, Sullivan, & O'Donnell, 2021). Citizen science projects increase the awareness of environmental issues (Heigl & Zaller, 2014; Mitchell et al., 2017) and allow students to contribute to the body of scientific knowledge (Mitchell et al., 2017). To be effective, however, the goals of the instructor should align with the goals of the project (Aivelo & Huovlin, 2020; Roche et al., 2020).

Despite the flexibility and potential benefits of including citizen science in undergraduate courses, challenges to implementation can arise. For example, students may be inclined to falsify data or rush through the data collection and reporting process if their grade is based on the amount of data contributed to a project (Mitchell et al., 2017; Roche et al., 2020; Tsujimoto et al., 2019). Creating grading criteria that emphasize quality over quantity, using citizen science platforms with built-in procedures for evaluating data accuracy, or instruction on the responsible conduct of research can reduce these risks (Lottfian et al., 2021; Resnik et al., 2015). In addition, logistical challenges to collecting and reporting data can occur, but these can often be eased by choosing a citizen science project with a clear structure and resources that emphasize ease of use (Bedell & Gates, 2021; Smith et al., 2021; Vitone et al., 2016).

Given the potential for citizen science to not only engage undergraduate students but also provide valuable large-scale, long-term ecological data, we were interested in determining how citizen science has been implemented in the online undergraduate classroom. We reviewed the current literature to (1) identify what types of courses and institutions report using citizen science, (2) list the projects and platforms that have been implemented in online courses in undergraduate

education, (3) examine how students participated in the projects through the online courses, and (4) summarize the learning objectives and reported benefits of student participation in the online course setting. The overall goal was to define the current use and identify knowledge gaps in the implementation of citizen science in the online undergraduate classroom.

METHODS

Eligibility criteria

The Online Working Group of the Undergraduate Student Experiences with Citizen Science Network (<https://qubeshub.org/community/groups/usecitsci>), a Research Coordination Network investigating the use of participatory science approaches (e.g., citizen and community science) in undergraduate classes, conducted a literature review regarding how citizen science has been used in online class formats. We sought literature that fit our definitions of (1) citizen science, (2) undergraduate education, and (3) online. We defined *citizen science* as a project or platform that members of the public can contribute to in some fashion (e.g., add data or analyze data) and that has some purpose outside of the traditional classroom. Therefore, projects used for classroom purposes only were not included. Throughout this paper, we use “projects” to describe citizen science that is driven by specific scientific questions and “platforms” to describe large public databases such as iNaturalist or eBird. We defined *undergraduate education* as post-secondary education in a formal class or research experience. Data related to primary and secondary or non-post-secondary informal education by adults (e.g., museums) were excluded. Our definition of *online* included citizen science in an online class (where class is partially or fully online) or an online or hybrid citizen science project that is used in a class even if class is taught in a face-to-face modality. Published journal articles in English with full text accessible in these databases up until August 2022 were included.

Search for relevant papers

A systematic literature search (Page et al., 2021) was conducted between April and August 2022 using Web of Science, SCOPUS, JSTOR, ERIC, blog searches, citizenscience.gov, and SciStarter (<https://scistarter.org>) to generate an initial list of articles for further inquiry. These databases cover a variety of scientific and educational journals in which instructors may publish papers

related to their use of citizen science with undergraduate classes. Search terms are shown in Figure 1.

Expanded search + check

Following the initial systematic search for papers in the sources listed above, an additional non-systematic search was conducted. Social media posts (twitter, LinkedIn) were published asking members of the citizen science community for recommendations on papers which fit the selection criteria. In addition, papers were added to the list based on authors' personal familiarity and experience in the field. The abstracts and titles of this full list of potential papers were then reviewed to determine if they met our search criteria or represented duplicates across databases. After this round of review, 33 papers remained. The reference lists and citations of these 33 papers were evaluated for inclusion and, where appropriate, added to the short list, which increased the total to 56 papers. The full text of these 56 papers underwent careful review against the inclusion criteria by two people, to produce a final list of 25 papers (Figure 1; Appendix S1: Table S1).

Coding and data analysis

Data to be extracted from the papers were determined based on the research questions. In total, up to 52 pieces of information were deductively coded for each paper, with each coder using the same fillable spreadsheet. Data collected included topics related to the course format and scope, participation style, learning objectives, assessment, and benefits to students from their participation (79 columns of data total). Data were extracted by two independent coders reading the full paper and indicating for each item whether it is present in the paper or not and coding the information that was present. Disagreements about how an item should be coded were resolved by discussion between coders and further clarification of the meaning of each code with the full authorship team.

RESULTS

Characteristics of papers meeting inclusion criteria

In all, 44 studies about the use of citizen science in undergraduate courses were found in these 25 papers in the published literature. The papers were published in a variety of journals, but the most common journal was

Citizen Science: Theory and Practice (Appendix S1: Table S1). Although the studies were from around the globe, a majority of those were published in English, and 35 (79.5%) were conducted in the United States. Publication dates ranged from 2010 to 2022, with 2021 having the highest publication rate of 9 (36%). Most of the studies were case studies or documentation of project implementation and responses from students. Only two studies (6.7%) included a control group to evaluate changes in attitudes or assessment from the exposure to citizen science projects.

Courses and institutions using citizen science

Citizen science projects were incorporated into multiple course formats and class sizes (Figure 2). Courses with a lab component (lecture/lab or lab-only) accounted for 53.4% of the studies. However, citizen science was part of lecture-only courses (20%) and independent research courses (16.7%) as well. Three studies did not report the course type. Forty percent of the courses had 30 or fewer students although many of the studies (46.7%) did not report class size information. Of the studies that reported class size, number of class sections included, and number of semesters included, the average number of students who had participated in citizen projects was 460, with a range from 5 students to 9662 depending on the number of years the course had included the project and how many sections of the course were offered. Fifty percent of the courses were described as introductory level (first or second year), but 30% of the studies did not report the course level. Students in these courses were often STEM majors (33.3%); however, the majors of students enrolled in the course were not reported for many of the studies (36.7%).

Projects and platforms being used

The citizen science projects ranged from topics on animal behavior to water monitoring (see Figure 3a). The most common projects consisted of classification of species or natural history (36.7%), corresponding with the large percentage of the courses that reported using citizen science in the field of Biology, particularly ecology (70%). Chemistry, Computer Science, General Science, GISs, and Physics courses also implemented citizen science. Most projects (70%) were online except for data collection. Only 20% of the citizen science projects were fully online and did not require field time or travel (Figure 3b). Appendix S1: Table S1 shows the complete list of the 21 citizen science projects reported, with

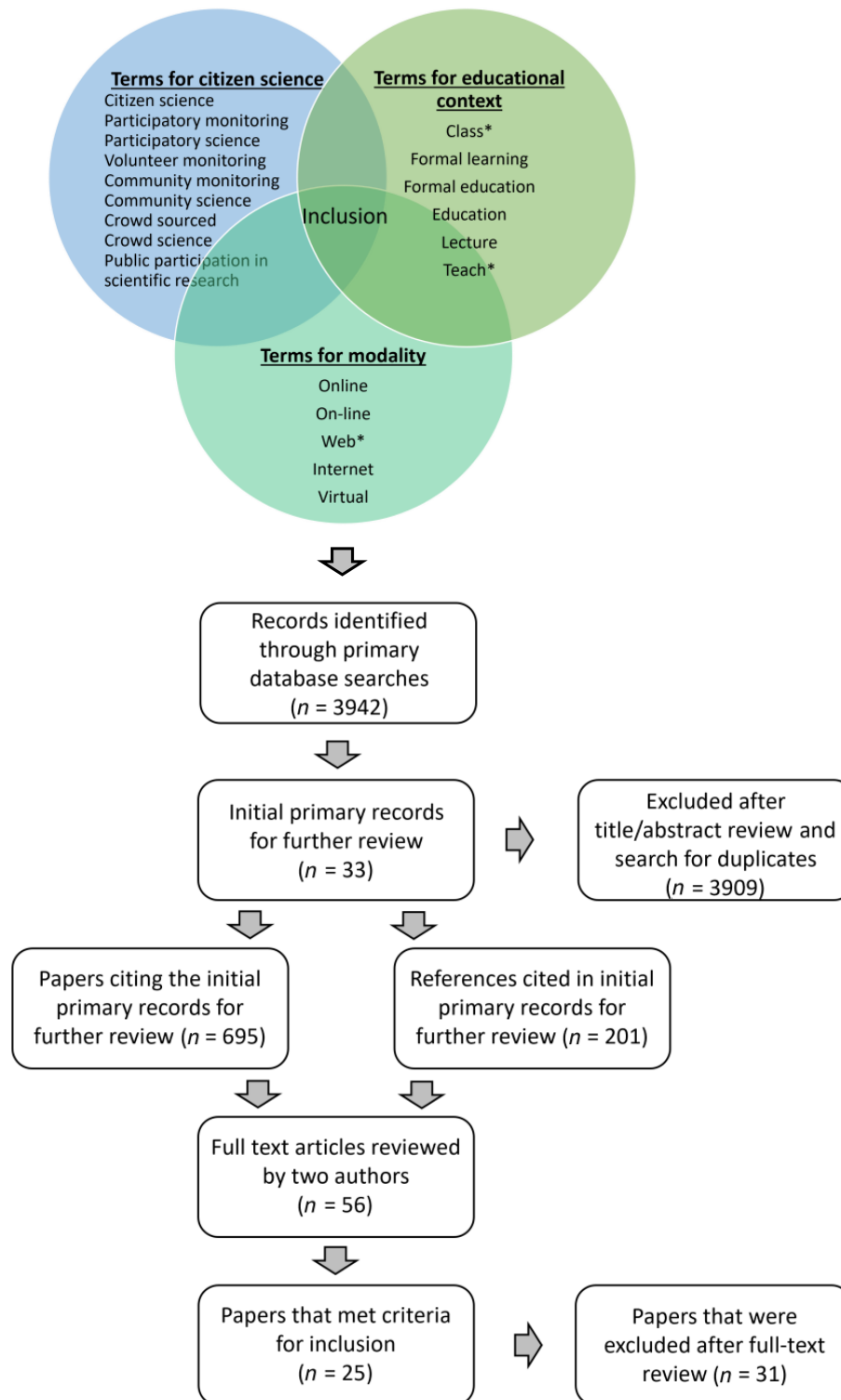


FIGURE 1 List of the terms used for searching and selection of articles is shown in the Venn diagram portion of the figure, in which the terms within a circle were used with an “OR” between them for searches while “AND” was used for searches between circles. The asterisk (*) indicates words that were searched with multiple possible endings (e.g., class, classes, classroom). The flow diagram shows the process used for selecting articles from the search to include. Database searches and rounds of review led to 25 papers that met our criteria for inclusion.

iNaturalist being the most frequently documented project (25%). Most projects (19 of the 21) were used only in one course, with iNaturalist being used in eight courses.

Three of the studies mentioned that they allowed students to select from a list of projects, but these lists were not specified in the publication.

How students participated

Students in these courses participated in the citizen science projects in a variety of ways (Figure 4). Most frequently, the students collected and submitted data to the project (77% and 87% of courses, respectively). Other

means of participation included using project training resources (57%), analyzing or graphing data (47%), or developing (27%) or testing (23%) their own hypotheses.

Learning objectives

The published papers included courses with various learning objectives for the use of citizen science in their classes. Most frequently, involvement in a project was intended to reinforce disciplinary content knowledge, the scientific process, or authentic research (>60% of courses, each). In other courses, introducing students to a means of contributing to science and society (47%), showing the relevance of science (43%), or generating excitement in science (43%) was emphasized. Only 20% of courses reported including citizen science to allow students to go through the entire scientific process with an independent question (e.g., Golumbic & Motion, 2021; Heigl & Zaller, 2014; Lichti et al., 2021; Mitchell et al., 2017).

Benefits of student participation

Of the courses reporting using citizen science, 63% included some sort of assessment of student learning

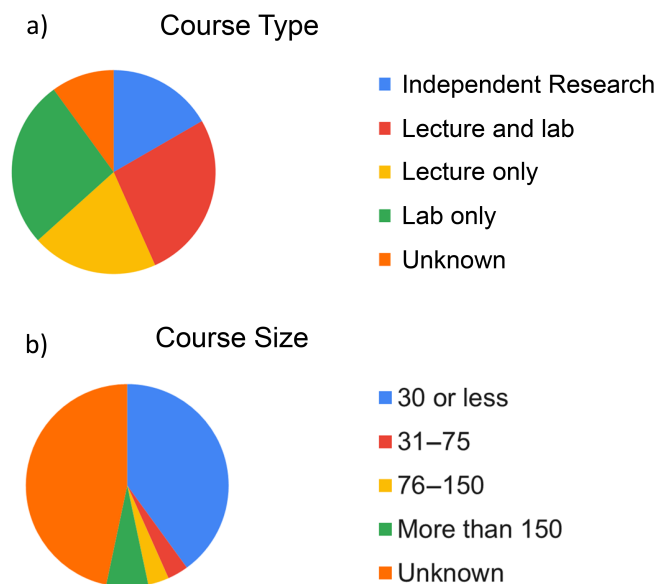


FIGURE 2 Types and sizes of courses reporting using citizen science.

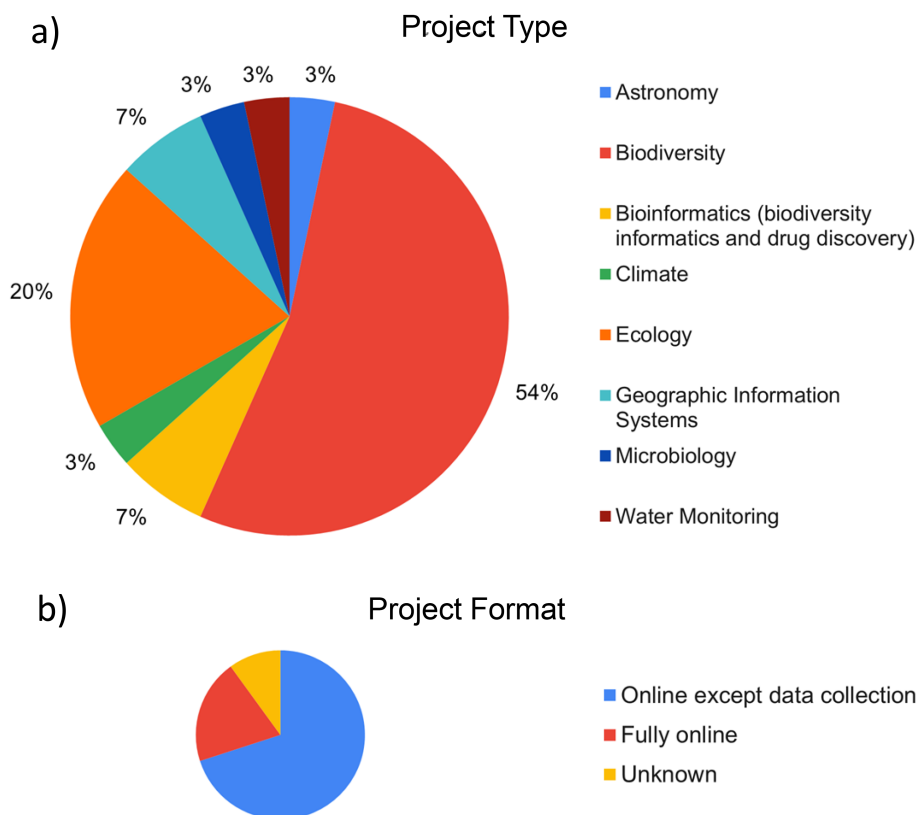


FIGURE 3 Citizen science projects used in undergraduate courses, divided into project type and modality.

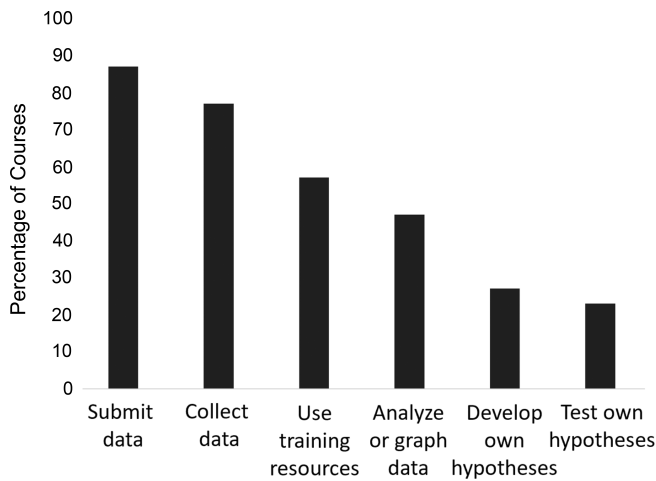


FIGURE 4 Students participated in citizen science in a variety of ways, shown here as the percentage of courses in which students took part in a specific aspect of the project.

outcomes (27% did not report any assessment and for 10% it is unknown). Two courses reported using published assessment instruments, in one case (Smith et al., 2021) from the DEVISE Project (<https://www.birds.cornell.edu/citizenscience/measuring-outcomes/>). One additional course (Lichti et al., 2021) modified an existing instrument, the Assessment of Scientific Argumentation in the Classroom observation protocol (Sampson et al., 2012; Walker & Sampson, 2013). In all other courses, the assessments were entirely written by the instructor.

Instructors assessed a variety of artifacts related to the student's involvement in the citizen science projects (Figure 5a), including student-generated papers and presentations (43% of courses), the number of samples/data points collected (30%), written reflections (27%), the hours/time students invested in the project (7%), and quiz or exam questions on topics related to the project (3%). These assessments generally gauged student engagement in the project (40% of courses), specific scientific skills relevant to the project (37%), motivation (33%), science content associated with the project (27%), or student self-efficacy (17%) (Figure 5b).

Statistical results of these assessments were not included in most published papers; instead, anecdotal reports of the impacts of student participation in citizen science were more often described. These anecdotal descriptions included that students gained scientific skills (e.g., learned to identify scientifically important items on images or identify species; Cardamone & Lobel, 2016; Oberhauser & LeBuhn, 2012; Paradise & Bartkovich, 2021), created scientifically useful data/products (Adams et al., 2012; Hitchcock, Sullivan, & O'Donnell, 2021), and were exposed to useful technology

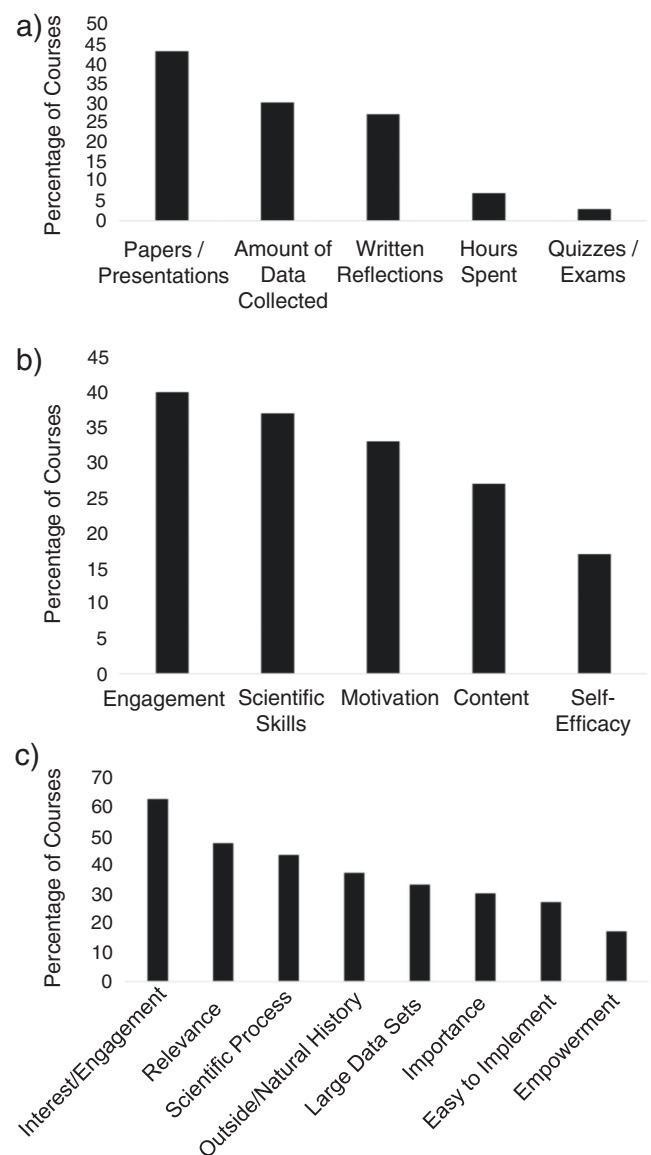


FIGURE 5 (a) Percentage of courses that used these forms of assessment after student participation in citizen science. (b) Percentage of courses that assessed these topics after student participation in citizen science. (c) Benefits gained from the use of online citizen science with undergraduates, described anecdotally by instructors and students.

(e.g., www.openstreetmap.org) and its potential use to address questions of societal concern (Bartoschek & Keßler, 2013). In addition, students appeared to have increased confidence (Gerhart et al., 2021; Phillips, Walshe, et al., 2018; Smith et al., 2021), were more engaged (Golombic & Motion, 2021; Kridelbaugh, 2016; Oberhauser & LeBuhn, 2012), enjoyed being outside or gained a better appreciation for nature (Gerhart et al., 2021; Hitchcock, Sullivan, & O'Donnell, 2021; Mitchell et al., 2017), and felt that they had contributed to science (Cardamone & Lobel, 2016; Golombic &

Motion, 2021; Hardy & Hardy, 2018; Mitchell et al., 2017). In one instance, the viewpoints of students about science were reported to have changed (e.g., their view of what research is expanded beyond lab work in isolation; Straub, 2020).

Many papers included anecdotal reports of students benefiting from their participation in citizen science (Figure 5c). These benefits include increased student interest/engagement (62% of courses), improved appreciation for the relevance of science to the “real world” (47%), providing an opportunity for students to use the scientific process (43%), giving students the opportunity to be outside or learn natural history (37%), requiring students to work with large datasets (33%), enhancing the feeling that students are contributing to something important (30%), and feelings of empowerment to participate in science (17%). An additional logistical benefit that it was easy to incorporate citizen science into a course was also mentioned by 27% of courses. Other benefits that were mentioned include that students could be given choice in the project they did, that the citizen science project gained additional data, and that these approaches could be implemented in a variety of class sizes and subdisciplines.

DISCUSSION

Characteristics of courses and citizen science being used

Most of the citizen science projects that were used with post-secondary students in online settings were in the areas of ecology and natural history, with iNaturalist being the most common platform used. As iNaturalist is a well-known, general platform to record the occurrence of a wide variety of taxa, it is an option that fits into many types of courses (e.g., entomology, mammalogy, ecology). Its large number of users who can verify species identifications of uploaded images, in addition to the artificial intelligence (AI) identification features, also makes it an attractive platform to use with students who are less experienced with identifying taxa. While it is possible that our finding that most use of citizen science was in the area of ecology or natural history was influenced by our search criteria, it is unlikely that our search criteria largely impacted these results. Multiple databases we searched are not discipline specific (e.g., SCOPUS, JSTOR), and prior research on citizen science has documented the higher representation of natural history or ecology than other subdisciplines (Follett & Strezov, 2015; Pettibone et al., 2017). The large focus of citizen science on topics related to ecology makes

Ecosphere readers a large potential pool of instructors interested in the implementation of these projects into undergraduate courses, including online courses.

The number of instructors using online citizen science with post-secondary students appears to be increasing (with more than a third of the papers coming from 2021 alone). In part, this is because citizen science participation itself is increasing, with the number of projects listed on platforms such as SciStarter, Zooniverse, or citsci.org increasing dramatically over the past two decades (Aceves-Bueno et al., 2017; Follett & Strezov, 2015; Golumbic, 2024). The increase in relevant citizen science projects available that are relevant to ecology and/or natural history, paired with the arrival of user-friendly mobile apps (e.g., to facilitate species identification), makes the incorporation of citizen science into ecology or biodiversity-related courses increasingly accessible to more post-secondary environments (Hitchcock, Vance-Chalcraft, & Aristeidou, 2021). Similarly, the availability of online instruction has become much more widespread after the COVID-19 pandemic (García-Morales et al., 2021). Therefore, it is unsurprising that we found a large percentage of papers discussing the use of citizen science in online higher education from after 2020, even though the earliest paper we found was from 2010.

The usage patterns we found in online citizen science in higher education were similar to those patterns that have been found previously in post-secondary settings more generally (Vance-Chalcraft et al., 2022). In both cases, citizen science has been used in a wide variety of post-secondary settings—from introductory courses to upper-level electives, classes with fewer than 30 students to much larger classes, and classes for STEM majors to those for students geared for careers outside of STEM fields. Students primarily are asked to participate in data collection in both online and other course formats, with hypothesis generation and analysis required less frequently.

Learning outcomes and benefits of student participation

As in other higher education settings, instructors had a variety of learning objectives for the online citizen science, but they most frequently wanted to reinforce disciplinary content or expose the students to authentic science. Instructors in both course settings (online and face-to-face) generally designed their own assessments for students, often requiring students to generate papers or presentations based on their citizen science data collection. Finally, very little rigorous assessment data are available on the effectiveness of using citizen science in

online settings, but instructors reported anecdotal evidence of benefits to students. This lack of rigorous assessment data stems in part from the fact that many of the papers we found were focused on either the scientific data the students collected or a general description of using citizen science in class with students. The papers were not written by education or discipline-based education researchers.

We encourage faculty using these approaches with students to publish on their efforts, providing details about their implementation, assessment, and course context. Using more intentional assessment of the benefits of participation in online citizen science will also allow for more rigorous analyses. In many papers, there appeared to be anecdotal evidence that the learning objectives instructors had for including citizen science in their course generally matched the benefits the instructors perceived the students gained through the experience. Research on this topic will be limited, however, until the literature has more examples of courses that plan out the learning objectives for citizen science experiences ahead of time and design assessments to evaluate the realized student learning outcomes.

The impact on students from involvement in online citizen science may have parallels to outcomes that have been found for people participating in citizen science through museums, nature centers, and other informal learning environments. Phillips, Porticella, et al. (2018) synthesized papers and literature from informal learning environments to articulate a framework of learning outcomes that participants may attain through their involvement in a project. These outcomes—interest, self-efficacy, motivation, content/process/nature of science knowledge, skills of science inquiry, and behavioral changes/stewardship—could be further investigated to determine if they also are attained by students in formal online post-secondary courses. While the ways students participate in citizen science are similar to volunteers in informal learning environments, potential differences in motivation and autonomy may influence the outcomes achieved.

Although meeting student learning outcomes is important for activities in a post-secondary classroom, other potential benefits of including students in online citizen science exist. For example, instructors appreciated the ease with which citizen science could often be implemented in an online course and the availability of relevant projects for a variety of subdisciplines, course sizes, and course levels. Environmental monitoring, in particular, can be done in a range of settings—from outdoor natural areas (e.g., identifying species) to indoor homes (e.g., identifying indoor arthropods or measuring lead in indoor water sources). In addition, ecological and

environmental sciences can benefit from the extra data being collected from students in a wide set of geographic locations and time periods (Theobald et al., 2015). Finally, society could benefit from having more people with a greater appreciation for science, helping to elevate policy discussions and increase awareness of environmental issues.

Citizen science can also benefit from the participation of students during their post-secondary studies. For example, most people currently participating in citizen science have been shown to be white, middle-aged, from the upper middle class (NASEM, 2018; Pateman et al., 2021). Student populations in many university courses more closely represent the diversity of society. Therefore, their involvement in citizen science helps diversify the participants over historical levels. Once these students leave a course, they have the potential to continue their participation with the project or join other projects now that they are aware of citizen science options (Hitchcock, Sullivan, & O'Donnell, 2021). Future research is needed to determine what projects or project characteristics make students more likely to continue after their class ends. One paper reported that a project's structure (i.e., video game interface) was a stronger predictor of a student's future use of a project than its content was (Bedell & Gates, 2021).

This research faced a number of limitations, particularly in regard to our search process and data availability. One limitation is that our search selected for papers in English and likely was biased toward papers from the United States. As with all literature searches, it is possible that there is a file drawer issue, in which individuals only choose to publish papers in which they see positive results. As these published papers were light on assessment data, however, we do not anticipate that many papers were rejected for finding no significant benefits to participants. Papers often did not include basic information about courses (number of students, online or face-to-face format, course level), which limited the number of comparisons we could make. Finally, the lack of reported assessment results made statistical analyses impossible for student learning outcomes. We recorded anecdotal benefits that were mentioned or strongly implied in a paper, but this may underreport benefits that instructors or students saw (but did not specifically report in their paper) to the use of citizen science.

CONCLUSIONS

The diversity of citizen science projects and platforms that are available provide flexible possibilities for a

variety of undergraduate course settings to engage students and expose them to authentic research. These options are particularly plentiful for ecological and biodiversity-related classes. The use of citizen science in online higher education appears to be increasing, but there are still many unknowns including learning objectives and assessments, evaluation, and whether instructors continue using it over multiple semesters after their original adoption. While improvements to student learning have been hypothesized based on anecdotal impressions of instructors and findings from informal learning environments, there is not enough data reported in published papers to rigorously test this hypothesis. Collaboration between education researchers, project evaluators, and instructors would help fill this gap and refine our understanding of which learning outcomes are met by student participation in citizen science in a particular course context. The need for undergraduates to develop strong critical thinking and problem solving skills is only going to increase as global environmental challenges demand creative, evidence-based solutions.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data (Vance-Chalcraft et al., 2025) are available on Figshare: <https://doi.org/10.6084/m9.figshare.29293466.v1>.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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