



# Integrating Citizen Science with Online Biological Collections to Promote Species and Biodiversity Literacy in an Entomology Course

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## ABSTRACT

The integration of citizen science into undergraduate STEM courses improves science practice skills, enables students to contribute to the global collection of species occurrence data, and may increase understanding and appreciation of biodiversity. We integrated citizen science with a traditional insect collection in an entomology course at a liberal arts college. The activity targeted improvement of species and biodiversity literacy skills using online biological collections and identification resources. The citizen science component required students to upload images of insects to an online resource (BugGuide). We used formative and summative assessments, as well as a survey of students' experiences and perceptions to determine effectiveness. Formative assessments were useful in developing appreciation of citizen science and insect identification skills, whereas summative assessments revealed variable levels of achievement of species and biodiversity literacy. Students reported that the resources were useful in identifying specimens and learning about biodiversity, but some did not feel they were contributing as citizen scientists. They expected to earn a higher grade on their collection than they did; the lower-than-expected grades were mostly due to errors in identification and curation. The assignment and assessments can be easily modified for any course that includes examination of biodiversity and a citizen science component, including introductory biology, non-STEM-major diversity courses, and upper-level zoology or botany. Our semester-long approach to integrating biodiversity content and concepts with citizen science and online biological collections promotes species and biodiversity literacy.

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## INTRODUCTION

The increasing rate of global biodiversity loss is one severe consequence of human activity (Ceballos, Ehrlich, and Dirzo 2017; Hooykaas et al. 2019). The combined effects of overexploitation and pollution have led to habitat destruction and resource disparities, leading to Earth's sixth mass extinction (Ceballos, Ehrlich, and Dirzo 2017). Because of humans' reliance on ecosystem outputs, biodiversity loss also threatens humans (Cardinale et al. 2012; Wagg et al. 2014; Schneiderhan-Opel and Bogner 2020). As biodiversity declines, so do opportunities for human engagement, generating public ignorance surrounding biodiversity importance and degradation (Rozzi 2013; Soga and Gaston 2016; Hooykaas et al. 2019). To actively protect biodiversity and support conservation efforts, people must first understand the value of biodiversity (Hooykaas et al. 2019; Schneiderhan-Opel and Bogner 2020). Biodiversity literacy, a form of scientific literacy, encompasses the key processes of biodiversity awareness and understanding (Moss et al. 2014; Hooykaas et al. 2019).

Biodiversity literacy is both the ability to understand and comprehend the concept of biodiversity and to possess knowledge of specific actions that lead to biodiversity conservation (Moss et al. 2014; Jensen, Moss, and Gusset 2017; Hooykaas et al. 2019; Schneiderhan-Opel and Bogner 2020). Biodiversity can be observed from the gene to the ecosystem, which creates obstacles for understanding the term and could explain lack of biodiversity awareness (Fischer and Young 2007; Hooykaas et al. 2019). Adding to the complexity, biodiversity issues are embedded within economic, ethical, ecological, and social interactions (Gayford 2000; Weelie and Wals 2010; Hooykaas et al. 2019; Schneiderhan-Opel and Bogner 2020). To simplify the concept for students or the public, one can begin with an important aspect of biodiversity literacy, species literacy.

Species literacy is the possession of in-depth knowledge of a species through identification, research, and observation (Aldhebiani 2018; Hooykaas et al. 2019). Recognition of a species can foster a connection between students and their living environment (Verboom, Kralingen, and Meier 2004; Cox and Gaston 2015; Hooykaas et al. 2019). Acquiring a thorough knowledge of multiple species can lead to an understanding of interactions between species and with their surrounding environments. Thus, species literacy provides the foundation for biodiversity comprehension and increases the probability of action regarding conservation (Roth 1992; Hooykaas et al. 2019). Hooykaas et al. (2020) found that species literacy is higher for professionals in the field than for the public, and for the latter may not be high enough to be aware of conservation issues. One solution to increasing species literacy is to use

online biological collections and citizen science-related identification tools and apps.

Citizen science has been used to engage student participation to advance digitization of natural history observations (Spear, Pauly, and Kaiser 2017; Wittmann, Girman, and Crocker 2019) and to monitor biodiversity (Cooper et al. 2007; Chandler et al. 2017) while also improving species and biodiversity literacy (Ellwood et al. 2015, 2018; Schneiderhan-Opel and Bogner 2020). Integrating citizen science projects into undergraduate courses can improve STEM teaching and learning through civic engagement (Oberhauser and LeBuhn 2012; Vitone et al. 2016) and influence development of science practice skills (Ballou 2012). For engagement with many natural history apps, undergraduate citizen scientists need only an electronic device and an internet or cellular connection, allowing them to become active and participatory in conservation efforts (Page et al. 2015; Ellwood et al. 2018; Schneiderhan-Opel and Bogner 2020). Short-term engagement in an undergraduate course could then lead to post-course or even lifelong engagement with biodiversity smartphone apps and conservation efforts. Although long-term data are not available, we have observed students continue to engage with these apps after the course is over.

To foster such engagement, new educational approaches can be employed that utilize access to biological collections (Linton et al. 2019; Ellwood et al. 2020). Grace (2006) and Schneiderhan-Opel (2020) suggest that to create sustainable changes in biodiversity protection, education must equip students with the knowledge and motivation to contribute to conservation. Biodiversity Literacy in Undergraduate Education ("Biodiversity Literacy in Undergraduate Education (BLUE)," n.d.) has focused on biodiversity data literacy, a more quantitative approach than mere conceptual understanding of biodiversity (Ellwood et al. 2020). Although Ellwood et al. (2020) recommend a data science approach, basic biodiversity literacy is crucial for monitoring and understanding the extent of biodiversity, its rate of loss, and its importance (Moss et al. 2014; Jensen, Moss, and Gusset 2017; Spear, Pauly, and Kaiser 2017; Hooykaas et al. 2019; Wyckhuys et al. 2019). A focus on civic engagement with online biological collections can achieve species and biodiversity literacy goals while facilitating students' contributions to citizen science efforts.

Undergraduate courses that focus on taxonomic groups, such as entomology and other "-ology" courses, are prime candidates for promotion of species and biodiversity literacy through civic engagement. Entomology is a key course to integrate biodiversity literacy approaches due to the ubiquity of insects, their interactions with humans, their importance to ecosystem services, and their documented recent global

declines (Hallmann et al. 2017; Forister, Pelton, and Black 2019; Wagner et al. 2021). Our objective was to integrate citizen science, online biological collections, and species and biodiversity literacy components with a traditional insect collection in an entomology course at a small liberal arts college. We report on the structure and assessment of this species and biodiversity literacy assignment.

## METHODS

As part of revisions for an upper-level entomology course at a small liberal arts college, one of the authors (CP, the instructor) developed revised learning outcomes (LOs) to encompass the concept of biodiversity literacy (**Table 1**). Using inspiration from the Biodiversity Literacy in Undergraduate Education (BLUE) initiative, the instructor integrated citizen science and a BLUE activity (Linton et al. 2019) into a standard entomology laboratory insect collection assignment. Linton et al. (2019) instructs students on how to determine if geographic distributions have changed over time for identified species using data from online biological collections.

In addition to assignment LOs, we also considered course LOs relevant to the assignment (**Table 1**). These LOs were assigned to a level in Bloom's Taxonomy for development of the assignment and for potential adopters. They also relate to recommendations of *Vision and Change*, the recent national call to transform undergraduate biology education, as they focus on the core competencies of the Process of Science and Communication and Collaboration, as well as the core concepts of Evolution and Information, as biodiversity is a result of the mechanisms of evolution and represents information stored in ecological systems (AAAS 2011).

## THE INSTITUTION AND THE COURSE

We conducted the study at a small southeastern liberal arts college in the United States (US) with an enrollment

of ~2,000 students. The college contains an ecological preserve and a farm on which to collect insects. Biology is the third most popular major, graduating an average of 60 seniors each year. Entomology is an upper-level course that satisfies a requirement for the major, although it is not a required course. It also counts toward the natural science requirement for the environmental studies major. The course is taken by biology majors to fulfill the organismal/ecological lab course requirement. There were 29 students enrolled in the course the semester the study took place (Fall 2019). Twenty-two were biology majors (11 seniors, 8 juniors, and 3 sophomores), four were environmental studies majors (3 seniors and 1 sophomore), one was a senior political science major, and two were undeclared sophomores. One student did not complete the course, but all others participated in the study and completed the assignment, although one other student did not complete the survey at the end of the course.

## THE ASSIGNMENT

The assignment consisted of a modified insect collection, a common laboratory assignment in entomology courses that often includes natural history observations and collection of specimens. The collection was a semester-long project, with multiple opportunities for collecting in groups or independently around or near campus. The project was scaffolded and linked to activities in the classroom. For instance, readings and classroom activities examined basic insect morphology and characteristics of major orders, and students applied that content with examination of physical specimens in the laboratory. A second example of scaffolding occurred in the classroom, where students studied geographic distributions and habitat requirements in the context of invasive species, and then distributions were examined for a subset of specimens collected.

Digital collection of specimens in a course can be integrated easily with online digital resources and collections, which may include museum specimens,

SPECIES AND BIODIVERSITY LITERACY ASSIGNMENT L.O.S STUDENTS WILL BE ABLE TO...	BLOOM'S LEVEL
<ul style="list-style-type: none"> <li>produce an insect collection in an appropriate manner;</li> <li>explain the extent and importance of insect diversity;</li> <li>describe the habitats and ecology of insects in your collection;</li> <li>collect, identify, and properly curate insects both actually and digitally; and</li> <li>use online biological collections to test hypotheses and ask questions regarding range shifts.</li> </ul>	<ul style="list-style-type: none"> <li>6: create</li> <li>2: understand</li> <li>2: understand</li> <li>3: apply</li> <li>4 and 5: analyze &amp; evaluate</li> </ul>
ENTOMOLOGY COURSE L.O.S RELEVANT TO THE ASSIGNMENT. STUDENTS WILL BE ABLE TO...	BLOOM'S LEVEL
<ul style="list-style-type: none"> <li>integrate, analyze, and evaluate the systematics, diversity, evolution, morphology, and ecology of insects;</li> <li>identify major orders and families of insects common in the area and those that are important to humans; and</li> <li>communicate concepts and results to peers and professionals.</li> </ul>	<ul style="list-style-type: none"> <li>5: evaluate</li> <li>1 and 2: remember &amp; understand</li> <li>3: apply</li> </ul>

**Table 1** Assignment and course learning outcomes (LOs) related to the species and biodiversity literacy insect-collection assignment. Each LO was assigned a Bloom's Taxonomy level (levels coded with one key term).

citizen science contributions, or both. Students can upload digital specimens to open access collections such as BugGuide (“BugGuide,” n.d.) and smartphone apps such as iNaturalist (“iNaturalist,” n.d.) to confirm identifications, to contribute to the collections, and to engage as citizen scientists. BugGuide is an online community whose mission is to create a knowledgebase for learning about and identifying insects and related arthropods. We focused on BugGuide, as students were required to make a tentative identification prior to uploading. iNaturalist is a network of naturalists, citizen scientists, and biologists sharing biodiversity information. Its use was optional, and students could contribute images only after identification, as iNaturalist suggests identifications, which could be used to circumvent the identification process. Both resources contain significant information on taxonomy, habitat, and ecology of species.

The assignment also asked students to investigate geographic distribution changes using a modified BLUE activity (Linton et al. 2019) that integrated their collections with digital and citizen science components. Linton et al. (2019), published on the QUBES website (“QUBES,” n.d.), describe how students can examine changes in species distributions using data from the Global Biodiversity Information Facility (“GBIF,” n.d.; see Supplemental File 1). GBIF is an international network aimed at providing open access to digitized biological collection data. Specimens that students uploaded to BugGuide, for instance, often end up on GBIF if they are validated by experts or skilled amateurs, demonstrating to students how citizen science contributes to research efforts.

The insect-collection assignment was revised from previous iterations of the course as a (mostly) digital collection that combined students’ images, notes on behavior, and location/habitat information. The digital nature of the collection was related to the citizen science component, as digitized specimens were required to be added to online biological collections. A portion of the collection was required to be physical, to learn and practice the art of specimen curation (see Supplemental File 1). Students were required to use dichotomous keys to gain skills in using such keys, but also to become familiar with distinguishing order- and family-level characteristics. Fifteen specimens had to be identified to the species, all others to only the family, with documentation of resources used to identify specimens, including tracing their path through the keys.

High-quality images of fifteen of forty specimens collected had to be uploaded, nominally after initial species identification, to BugGuide. The BugGuide community would then confirm or correct the identification; poor quality images were rejected. In those cases, students

could upload a replacement image or suffer a deduction in their earned score. Instances of uploaded images that were never identified were rare and were handled in one-on-one consultation with the instructor. Although it was preferable to have high-quality images, this was not always possible, so physical specimens might have been collected on the instructor’s advice for specimens known to be difficult to identify even to the family level. Other specimens were distinctive enough that even a poor-quality image could be identified to the species. In those cases, keys were not required, but using keys was required for a subset of specimens.

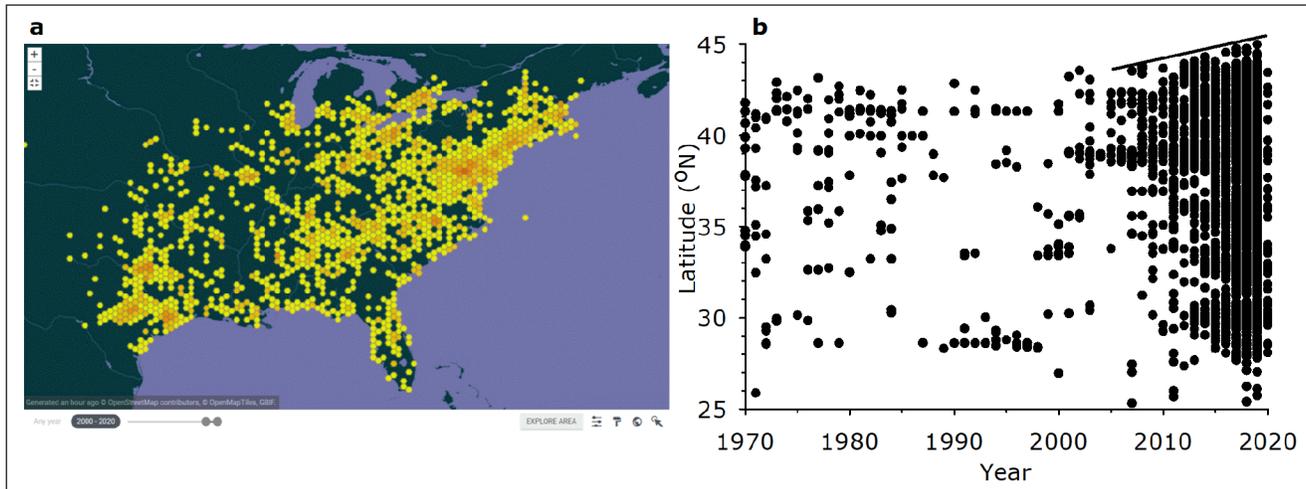
For all specimens identified to the species, students were required to download occurrence data from GBIF (“GBIF,” n.d.). The objective was to investigate species’ range shifts. Using these data, it is possible to estimate species ranges and examine potential range changes over time (Kharouba et al. 2018; Linton et al. 2019). Detailed instructions were provided (see Supplemental File 1); in addition, the instructor demonstrated how to download and export data into Excel. We also discussed in depth the quality of the data and the potential biases inherent in using data that is a combination of museum specimens and citizen science contributions. For instance, there is often a paucity of data prior to 2000, potentially biasing estimates of geographic range shifts (observed in *Figure 1a*).

To investigate species ranges over time, students examined occurrence records using maps generated on the GBIF website. Maps initially contain all records of a species, but a slider function allows examination of maps for different time ranges. Students could examine and take screenshots for distributions in 20-year increments, for example (*Figure 1a*). Depending upon the species, the time range could be adjusted, as many species lack data for some time spans. Screenshots would then be incorporated into their digital collection with a short paragraph interpreting the maps. Alternatively, students could download data from GBIF, import it, clean it, and create scatterplots of latitude versus year (*Figure 1b*). Students would then paste maps or scatterplots into their digital collection and write a short interpretation of their findings.

At the end of the semester, students turned in physical specimens and digital documents, a BugGuide username that allowed the instructor to access their citizen science contributions, GBIF-downloaded data and interpretations, natural history observations, and resources used. The format was open; students organized their collections in PowerPoint, Word, Excel, or Google Drive.

## ASSESSMENT

In addition to the biodiversity and species literacy assignment in the laboratory, we included several



**Figure 1** Examples of GBIF output using the eastern carpenter bee (*Xylocopa virginica*). **(a)** Map showing observations of carpenter bees from 2000 to 2020. **(b)** Scatterplot of occurrence records of *X. virginica* from 1970 to 2020. More occurrence data is typical for many species after 2000 owing to the increased frequency of citizen science data and digitized biological collections. The slanted line at the top of the points after 2005 indicate the student's hypothesized northward range expansion of several degrees latitude. Data obtained from: GBIF.org (23 March 2020) GBIF Occurrence Download <https://doi.org/10.15468/dl.s1ylux>.

biodiversity-themed readings and in-class discussions on insect evolution, ecology, and conservation. These assignments were routinely related to the collections or any specimens we had observed as a class while on field trips. For instance, an article on bee pollinator diversity offered opportunities to discuss local bees that we had observed in the field.

We assessed numerous components of the collection and related assignments, both formatively and summatively. Formative assessments included checking student identifications frequently while working on collections, asking them to show or informally report on their progress toward meeting diversity requirements or their GBIF downloads, and informally quizzing them in the field and in class by asking them to identify or comment on an insect. This might then lead to speculation and discussion of ecology and behavior of the species, reinforcing species literacy.

Summative assessment of the collection included examination of all components of the collections using a rubric provided to the students prior to the due date (see Supplemental File 1). We analyzed the mean score and the percentage of students who earned a grade of B or better ( $\geq 83\%$ ) for each component of the rubric. Analysis of those components is likely to yield insights on achievement of both species and biodiversity literacy. A grade of B or better for proper identification of 40 specimens from 30 families would demonstrate a high level of both species and biodiversity literacy. The mean score for the collection was compared with the overall course grade for each student using a paired t-test.

At the end of the semester, students were asked to complete a survey to self-report their experiences with

the collection and the utility of the resources (BugGuide, iNaturalist, and GBIF). Students provided overall ratings for these components, and whether they agreed or disagreed on a 5-point Likert scale that the resources (BugGuide primarily, and iNaturalist if they used it) were helpful to their identification efforts, that they were contributing to the biological collections when they uploaded images and associated data to the resources, that their understanding and appreciation of insect biodiversity was enhanced using the resource, and that they were likely to continue to use the resource. We used a one-way ANOVA to determine whether mean overall ratings of the three resources differed from one another. Although some research suggests that “feelings of learning” do not equate with actual learning (Deslauriers et al. 2019), our survey primarily assessed the resources, not perception of learning.

For GBIF, students were asked whether they agreed or disagreed that GBIF was useful in helping them understand the utility of open access biological collections, that their understanding and appreciation of insect biodiversity and geographic distributions was enhanced, and whether they were likely to continue to refer to GBIF to answer questions about a species or its distribution. For the collection itself, students were asked whether they agreed or disagreed that their appreciation for biodiversity has increased, that diversity requirements were reasonable, that the collection is a useful assignment for learning about local biodiversity, and whether they believed their specimens were accurately identified. The answers to these survey questions were helpful in judging the overall scope of the collection assignment in the context and goals of the overall course. Finally, students were asked to anticipate their grade on

the collection after having reviewed the rubric and added comments on any of the resources or the overall collection assignment. A two-sample t-test was used to compare the mean anticipated grade with the mean actual grade for the overall collection.

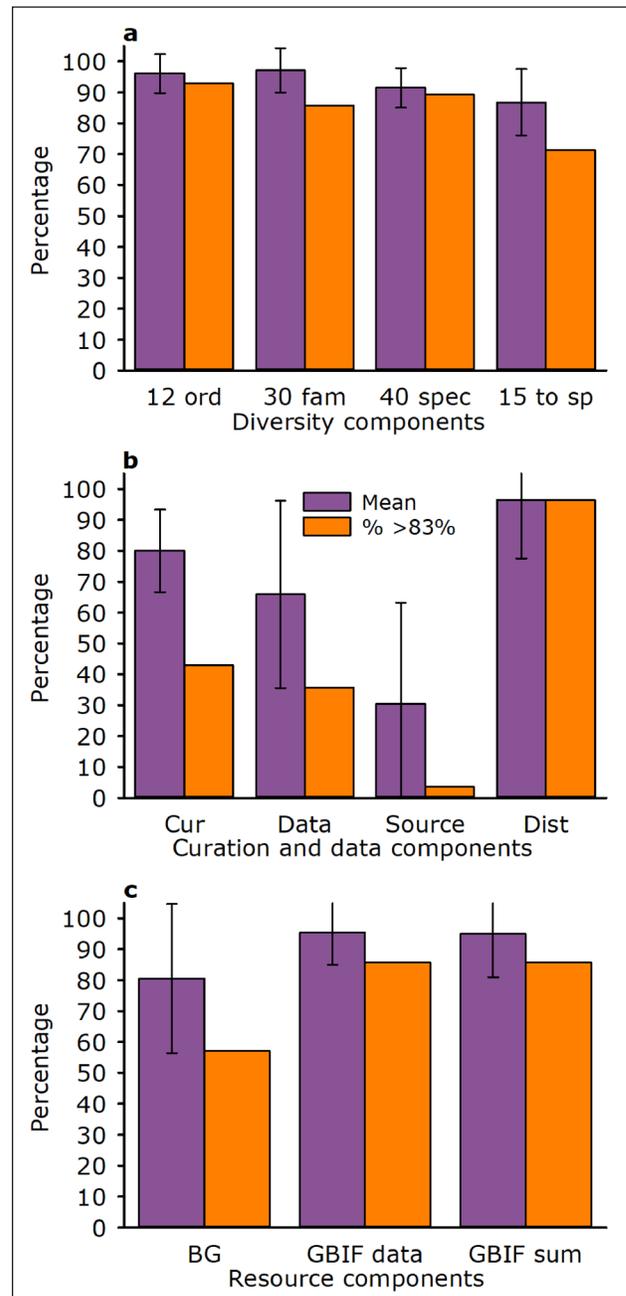
## RESULTS

The instructor noted that many, but not all, students became strongly engaged in the insect collection and identifications. When informally quizzing students in the field or in class, or even once during a departmental seminar with several students in attendance, it was clear that many of them were becoming quite adept with their knowledge of insect identification and biodiversity. Formative assessment was used mainly to diagnose student progress in real time, to help correct mistakes while identifying specimens, to advise students in the field, and to keep students on track for this semester-long assignment. All data for assessment of the collection and survey results can be found in Supplemental File 2.

### ASSESSMENT OF THE COLLECTION

The overall average grade on the collection was 86.1% + 6.7% (SD). The mean students' anticipated grade was 0.5 GPA units greater than the overall average grade for the collection (expected grade =  $3.56 \pm 0.08$  [SE], actual grade  $3.06 \pm 0.13$  [SE],  $t_{53} = 3.16$ ,  $P = 0.003$ ). A paired t-test revealed that the collection grades were significantly lower than overall course grades (collection grade  $3.06 \pm 0.13$  [SE], course grade =  $3.40 \pm 0.08$  [SE], paired  $t_{53} = 3.27$ ,  $P = 0.001$ ). GPA was used here rather than percentage because students reported their anticipated grade as a letter grade on the survey.

Students scored high, on average, on the diversity components of the rubric (*Figure 2a*), with > 70% earning a B (83%) or greater on each component. Despite high scores, no student successfully identified all 40 species to the family level, and less than 20% successfully identified 15 species to the species level. Students scored lower on curation, and only 40% of students earned  $\geq 83\%$  of points for curation (*Figure 2b*). This was similar to database management and presentation, and scores were even lower for providing complete and accurate information for identification references. Students scored highly on adding distribution data on their specimens (e.g., where it was caught, type of habitat). Specimens uploaded to BugGuide were variable in image quality, and only 57% of students earned  $\geq 83\%$  by uploading high-quality images; the mean score was 80% but was highly variable (*Figure 2c*). Students earned high scores on the two GBIF components (maps or scatterplots



**Figure 2** Mean grades as percentages (purple bars;  $\pm 1$  SE) and percentage of students achieving scores of  $\geq 83\%$  (orange bars) on components of the insect collection. The latter is based on percentage of students, and as such does not have an error term associated with it. **(a)** Diversity components of the collection, including containing 12 orders, 30 families, 40 specimens, and 15 species-level identifications, all identified correctly. **(b)** Logistics of the collection, including curation, data management, sources, and notes on distribution. **(c)** BugGuide and GBIF components of the collection, including uploading images to BugGuide, downloading of data from GBIF, and interpretation of GBIF data.

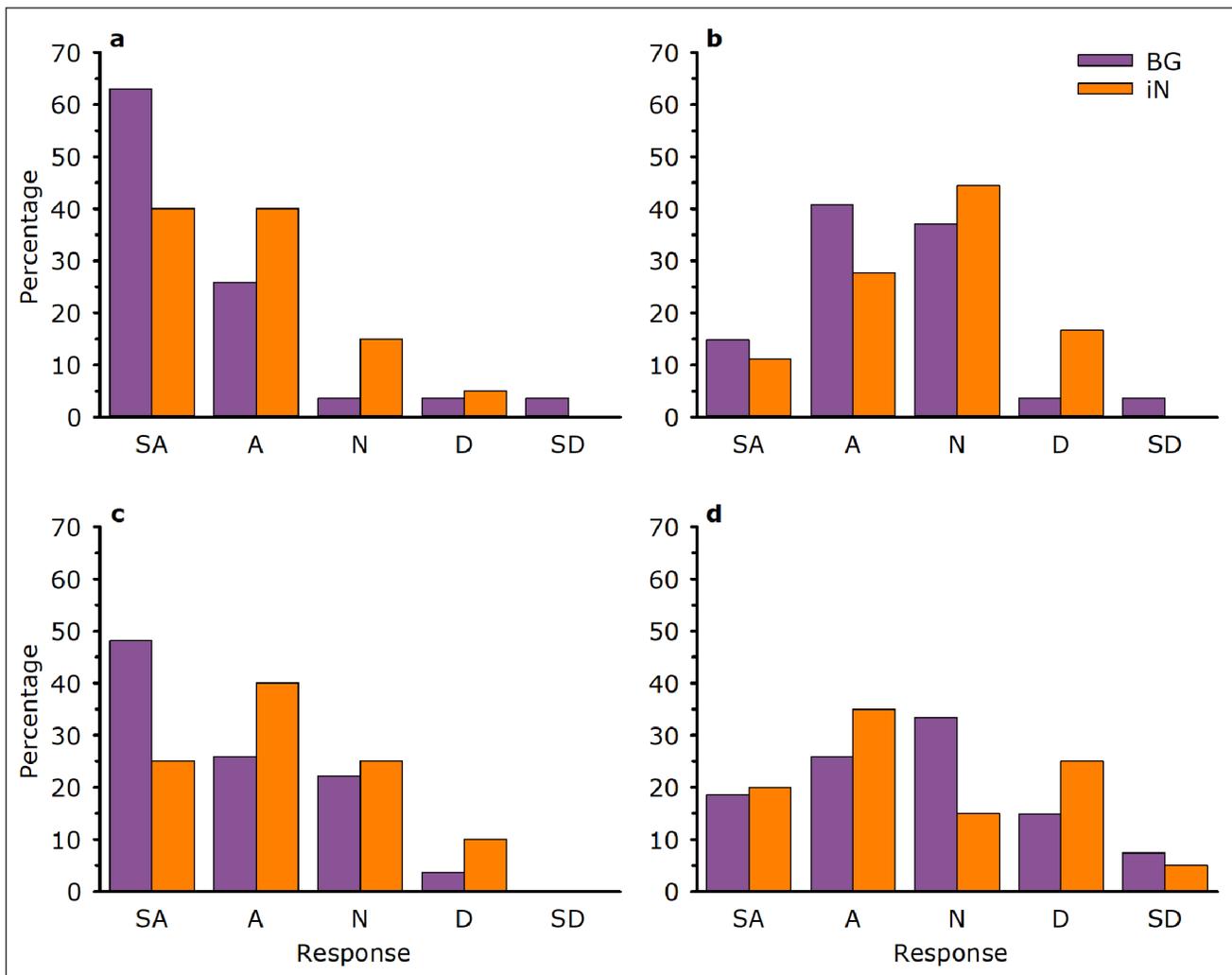
from downloaded data and a summary interpretation of their data; *Figure 2c*). A high percentage of students earned  $\geq 83\%$  of the points for the GBIF components of the rubric, suggesting high engagement.

## SURVEY RESULTS

We found that almost 90% and 80% of students strongly agreed or agreed that BugGuide and iNaturalist, respectively, were resources that helped them identify their specimens (*Figure 3a*). More students (approximately 40%) were neutral in assessing their contributions to citizen science, although still more agreed than disagreed (*Figure 3b*). Almost two-thirds to three-quarters of students strongly agreed or agreed that their understanding and appreciation of biodiversity was enhanced through use of the resources (*Figure 3c*). Responses to the question about continuing to use the resource after the course was over were much more spread out, with the highest percentages of disagree or strongly disagree out of all four BugGuide and iNaturalist questions (*Figure 3d*).

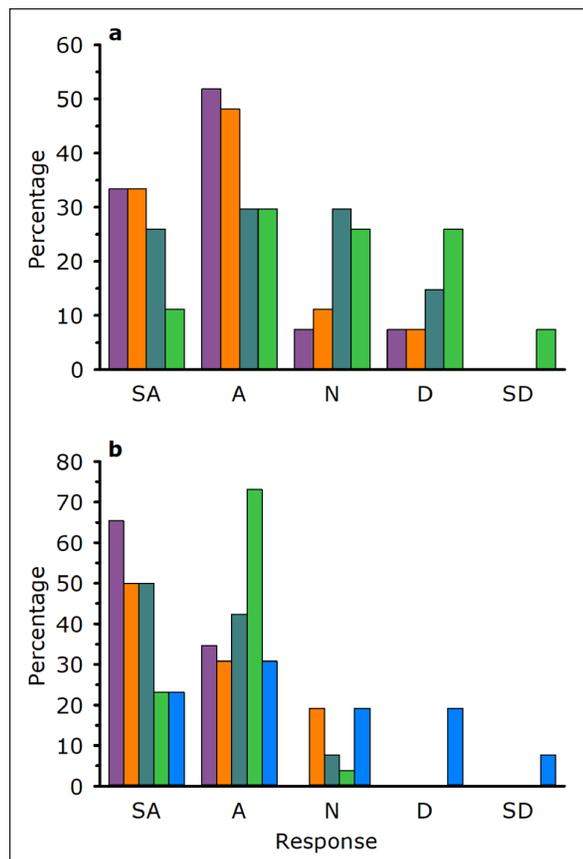
We found that more than 80% of students strongly agreed or agreed that their understanding of geographic distributions and the utility of open access collections was enhanced (*Figure 4a*). Fewer students (55%) strongly agreed or agreed that their understanding and appreciation of insect biodiversity was enhanced by using GBIF, and only 41% strongly agreed or agreed that they were likely to continue to use GBIF in the future. More than 25% of students disagreed with that latter statement, and it was the only GBIF question for which any students strongly disagreed (*Figure 4a*).

All 27 students who completed the survey strongly agreed or agreed that their appreciation for insect biodiversity increased as a result of making their insect collections (*Figure 4b*). Eighty to ninety-six percent of students strongly agreed or agreed that the diversity requirements were



**Figure 3** Results of student self-reported assessment of BugGuide (BG: purple bars) and iNaturalist (iN: orange bars) survey questions. (a) Responses to “the resource was helpful in identifying insects.” (b) Responses to “I felt that I was contributing to entomology when I uploaded images to the resource.” (c) Responses to “My understanding of insect biodiversity was enhanced using the resource.” (d) Responses to “I am likely to continue to use the resource.” Sample sizes were 27 for BugGuide responses and 20 for iNaturalist responses (not all students used iNaturalist). SA = strongly agree, A = agree, N = neutral, D = disagree, SD = strongly disagree.

reasonable for a semester long project, the collection was a useful assignment for learning about local insect biodiversity, and that they believed their specimens were



**Figure 4** Results of student self-reported assessment of GBIF (a) and the insect collection assignment (b) survey questions. Sample sizes were 27. SA = strongly agree, A = agree, N = neutral, D = disagree, SD = strongly disagree.

(a) GBIF questions were:

- “My understanding of geographic distributions was enhanced using GBIF” (purple),
- “GBIF was helped me understand the utility of open access collections for studying entomology” (orange bars),
- “My understanding of insect biodiversity was enhanced using GBIF” (teal bars),
- “I am likely to continue to refer to GBIF when I have questions about a species or its distribution” (green bars).

(b) Collection questions were:

- “My appreciation for insect biodiversity has increased as a result of this assignment” (purple bars),
- “The diversity requirements of this assignment were reasonable for a semester-long project” (orange bars),
- “The insect collection is a useful assignment for learning about local insect biodiversity” (teal bars),
- “I believe that my specimens are accurately identified” (green bars), and
- “I am likely to continue to collect insects images to upload to BugGuide or iNaturalist” (blue bars).

accurately identified. Unlike the first three questions, the latter question had a much higher percentage of “agree” than “strongly agree” (73% to 23%; **Figure 4b**). Finally, 27% of students disagreed or strongly disagreed that they were likely to continue to collect images to upload to either BugGuide or iNaturalist.

Along with the high percentage of students strongly agreeing that BugGuide was a helpful resource, the overall ratings on a scale of 0 to 10 of BugGuide were slightly higher than for iNaturalist and GBIF, but ratings for the three resources were not significantly different from one another (BugGuide =  $7.4 \pm 0.4$  [SE], iNaturalist =  $6.4 \pm 0.6$  [SE], GBIF =  $6.2 \pm 0.5$  [SE];  $F_{2,73} = 1.68$ ,  $P = 0.19$ ). However, it should be noted that iNaturalist was suggested as a resource but not required, whereas one component of the overall collection required use of BugGuide (adding images to the site) or GBIF (downloading occurrence data).

## DISCUSSION

The redesign of the entomology course described here, which integrates traditional collecting, citizen science/civic engagement, and open access digital biological collections, promotes species and biodiversity literacy. Traditional collections for entomology classes tend to be very local and solitary efforts, but the citizen science component encourages students to become part of a larger community. Students discover more about individual species (e.g., distribution and natural history) as well as insect biodiversity while contributing to online resources. Modern digital resources harness the power of citizen science, open education resources, and the science community (Bonney et al. 2009; Page et al. 2015; Ellwood et al. 2018; Schneiderhan-Opel and Bogner 2020). Inclusion of these resources illustrates that science is and should be a collaborative effort (Wittmann, Girman, and Crocker 2019; Schneiderhan-Opel and Bogner 2020).

Species and biodiversity literacy is critical to understand and appreciate declines in biodiversity and the effects of those losses to ecosystem services (Cardinale et al. 2012; Soga and Gaston 2016; Ceballos, Ehrlich, and Dirzo 2017). This understanding is critical in entomology owing to the maligned perception of insects and recent documented declines in global insect abundance and biodiversity (Hallmann et al. 2017; Forister Pelton, and Black 2019; Wagner et al. 2021). Biological collections are an important component of entomology (Kharouba et al. 2018), and online collections can be used by students to contribute their observations via easy-to-use smartphone applications and as a source of information about individual species and taxonomic diversity. Both types of literacy are important

to alter student and citizen perceptions and to encourage them to help reverse further declines in abundance and diversity (Grace 2006; Ellwood et al. 2020; Schneiderhan-Opel and Bogner 2020).

## ASSESSMENTS

We used earned scores on the collection rubric to assess learning and achievement of LOs and species and biodiversity literacy gains, which we justify based on the nature of the assignment. An insect collection is a semester-long engagement with entomological concepts and species and biodiversity literacy. Ability to accurately identify specimens and ability to build a diverse collection clearly suggest achievement of species and biodiversity literacy outcomes, as well as collection-related LOs.

Students thought they would earn, on average, between a B+ and A- on the overall insect collection, including use of the online biological collections. The actual mean grade was a B. Because this assignment is built around students constructing species and biodiversity literacy over the semester, their anticipated grade reflects, in part, their competency in those areas. Although this overconfidence in evaluating their work is common, overconfidence can negatively affect both personal and academic development (Hall and Sverdlik 2016; Magnus and Peresetsky 2018; Deslauriers et al. 2019). Closer examination of rubric scores revealed that the lower earned grade was mostly due to inaccurate identifications (at both the family and species level), sloppy citations of identification sources, and poor organization and curation of the collection (even a digital collection needs to be organized and curated properly) (*Figure 2*). Although inaccurate identifications reduced scores, most students accurately identified most specimens, an indication of species literacy.

A high percentage of students achieved the biodiversity components of the collection (*Figure 2a*), demonstrating achievement of learning outcomes associated with understanding of biodiversity (*Table 1*). Although most students achieved the LO of producing a collection in an appropriate manner, the LO on proper curation of specimens was not achieved for all students and specimens. Through their collection, students accurately used online biological collections to test hypotheses regarding range shifts of species. Students also demonstrated understanding of the extent and importance of insect diversity and an ability to identify major orders and families that are common in the area and those that are important to humans. Understanding the implications and importance of biodiversity, its loss, and its conservation is enhanced through examination of local biodiversity and global biodiversity issues (Moss et al. 2014; Hooykaas et al. 2019).

A high percentage of students achieved the LO on describing habitats and ecology of insects in their collection, evidenced by their descriptions of insects they caught, which suggests enhanced species literacy (Aldhebiani 2018; Hooykaas et al. 2019). However, early in the semester, prior to much collection and associated identification, which provides hands-on experience with identifying characteristics, students had difficulty listing defining characteristics of insects, an aspect of species literacy (data not shown). Later in the semester, many students exhibited difficulty identifying species we had discussed in class or observed in the field, which the instructor noted during formative assessment and one-on-one consultations. In-depth knowledge of species is idiosyncratic and contingent on an individual's collecting experiences, so achievement of species literacy goals may vary (Hooykaas et al. 2019). This suggests instructors should emphasize to students that knowledge of individual species can be made through observation and reading the literature (Cox and Gaston 2015; Hooykaas et al. 2019; Ellwood et al. 2020).

Many students did not upload quality images properly to BugGuide, which reveals that students did not create their collection in a professional manner, one of the LOs for this assignment. Although instructions for uploading images to BugGuide are present on the BugGuide website and are easy to follow, a detailed handout and demonstration from the instructor would likely have facilitated more participation and attentiveness with this civic engagement component. Overestimation of the collection grade was partly due to their assessment of the quality of their work. The insect collection is a semester-long project that takes dedication and diligence. Students that procrastinate typically do not do well, even if they are performing well in other aspects of the course, including other species and biodiversity literacy-related components.

Lack of attention to detail leads to lower realized grades, but it was encouraging to find that the diversity and GBIF scores on the collection rubric were in the A- range, and a large percentage of students achieved that level of proficiency. We conclude that students were able to use GBIF as a source of data to ask questions about range shifts, one of our LOs. The ability to use online biological collections as a source of data to test hypotheses is critical for the next generation of biodiversity data scientists (Ellwood et al. 2020).

## SURVEY

Students found both BugGuide (required) and iNaturalist (optional) were helpful resources and contributed to their biodiversity understanding. This perception may have been overestimated (Deslauriers et al. 2019), especially when

considering their anticipated collection grade versus their actual grade, yet many students achieved collection-related LOs. Written comments on the survey, while mostly positive, revealed some frustration, especially with the BugGuide interface and upload process. Positive comments were mostly about how helpful BugGuide and iNaturalist were in confirming identifications. Some students liked BugGuide better than iNaturalist, and some vice versa; there was no clear consensus. Use of these resources aided students in achieving LOs related to explaining the extent of diversity, to understanding insect habitats and ecology, and to identification of specimens.

Students did not strongly consider that uploading their specimens to biological collections were contributing to citizen science efforts. This was likely because of the previously mentioned frustrations with the BugGuide upload process and the instructor not stressing that aspect of the assignment as much as other aspects; contextualizing the assignment as an important contribution to citizen science is critical and should be strongly emphasized (Ellwood et al. 2020; Schneiderhan-Opel and Bogner 2020). BugGuide and the collection itself were more influential in affecting student perception of their biodiversity knowledge than GBIF. This is likely because of the identification capacities of BugGuide, an important aspect of how the survey results can be used to guide future courses that incorporate citizen science and specimen identification.

Students reflected that their understanding of geographic distributions and of the utility of online collections was enhanced, mostly through use of GBIF. This suggests that GBIF can be a key resource in courses where geographic distributions, range shifts due to climate change, and spread of invasive species are discussed. Overall evaluations of the three resources were above 60%, but with a fair amount of spread. Many students that take our entomology course as an organismal/ecological course requirement are in the pre-medicine and allied health program or are interested in molecular biology, which may explain why few of them planned to continue to use online biological collections.

## REFLECTIONS

Fall 2019 was unusually warm and dry in the North Carolina Piedmont (Marusak 2019). Insect abundance on campus was much lower than observed in previous autumns (CP, personal observation). Although that resulted in lower diversity of collections because students all had the commonly observed and collected species, it offered a teachable moment of the impacts of climate change on insects, and allowed more collaboration on developing species literacy skills, as students worked together on common specimens. Natural history and field components

of courses must take advantage of the actual conditions experienced by students, in terms of climate, urbanization, and many other environmental and anthropogenic factors. That requires instructors' deep knowledge of local natural history.

One issue with our pedagogical study is that there is no comparison group that shows how students perform on the collection in the absence of biodiversity literacy instruction. This is difficult to achieve in an educational setting. We overcome this limitation by assessing the percentage of students that achieved a particular level of proficiency on various components of the collection rubric. Another limitation is that we use student self-reporting as a mechanism of assessment. However, many of the survey questions asked students to assess the resources, not their own knowledge or learning. Despite these issues, we conclude that the use of open access biological collections such as BugGuide, iNaturalist, and GBIF can be done easily, cheaply, and thoughtfully to promote species and biodiversity literacy of undergraduate biology majors.

The assignment described here can be easily modified for any course that includes a traditional natural history or collection component to promote species and biodiversity literacy. This includes courses such as botany, invertebrate zoology, vertebrate zoology, or any more specialized taxonomic group. Although we did not require use of iNaturalist, we introduce and assess the student experience of it, as BugGuide would be useful primarily for entomology courses. The assignment is not just limited to traditional “-ology” courses, however. The assignment can be modified for inclusion in introductory biology, ecology, or even environmental science courses using iNaturalist and GBIF. For instance, in introductory biology, one author (CP) has developed an on-campus bioblitz using iNaturalist, which helped students identify specimens beyond the capabilities and taxonomic constraints of BugGuide, after which student teams select species to investigate natural history and geographic distributions using GBIF. The use of GBIF offers an opportunity to discuss possible spatial and temporal biases when attempting to answer questions about range shifts over time. The assignment is now fully integrated into his introductory biology course.

Additionally, educational institutions in urban settings have opportunities to enhance species and biodiversity literacy by exploring adaptations that facilitate or prevent species from living in urban environments, by studying species and habitat conservation, and by promoting citizen science efforts, all important aspects of conservation action (Grace 2006; Page et al. 2015; Ellwood et al. 2018; Schneiderhan-Opel and Bogner 2020).

## CONCLUSIONS

Improvement of education practices related to biodiversity science is critical (Ellwood et al. 2020). While Ellwood et al. (2020) recommend a data science approach, basic knowledge of species and biodiversity literacy is crucial to understanding the extent of biodiversity, its rate of loss, and its importance to providing ecosystem services (Moss et al. 2014; Jensen, Moss, and Gusset 2017; Hooykaas et al. 2019; Wyckhuys et al. 2019). We found high engagement with collection activities and conclude that while students may not have gained as much on identification skills, they achieved LOs related to using online biological collections, which can be used to promote citizen science goals and sources of species and biodiversity information. Our semester-long approach to integrating citizen science, civic engagement, and biodiversity content and concepts in an upper-level entomology course promotes species and biodiversity literacy. Both types of literacy are critical to alter student and citizen perceptions and reverse declines in abundance and diversity.

## DATA ACCESSIBILITY STATEMENT

Survey data and anonymized collection grade data are available for download at: <https://drive.google.com/file/d/1oIqxeJIIdX4pJF0UuQrC6PONTBxHr9QSI/view?usp=sharing>.

## SUPPLEMENTARY FILES

The supplementary files for this article can be found as follows:

- **Supplemental File 1.** Student instructions for GBIF, instructions for the insect collection, rubric for assessing the collection, and survey questions. DOI: <https://doi.org/10.5334/cstp.405.s1>
- **Supplemental File 2.** Survey data and anonymized collection-grade data. DOI: <https://doi.org/10.5334/cstp.405.s2>

## ETHICS AND CONSENT

This research was completed under approved HSIRB protocol #2019-117 at Davidson College.

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## COMPETING INTERESTS

The authors have no competing interests to declare.

## AUTHOR CONTRIBUTIONS

CP conceptualized and carried out data collection, analysis, and interpretation. LB and CP drafted, wrote, and prepared the manuscript for publication.

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