The iNaturalist Application in Biology Education: A Systematic Review

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Abstract: The iNaturalist application has been gaining traction in both biodiversity research and education. Increasingly more research is being carried out, looking into using the iNaturalist application in biology education, to promote biodiversity and educate students about this topic. We used the PRISMA systematic literature review method to examine research carried out using the iNaturalist application in biology education by searching Web of Science and Scopus, and including citizen science in the process. We searched through the iNaturalist forum, where users contribute research performed using iNaturalist. We found that an increasing number of articles have been published on this topic over the years. Researchers are using iNaturalist to improve BioBlitz activities, to enhance outdoor education activities, and to help make herbaria. Summarizing the work performed in this area, we suggest guidelines for including and preparing the iNaturalist application in a school context to be used by teachers and researchers alike.

Keywords: *BioBlitz, biology education, citizen science, iNaturalist, outdoor education.*

Introduction

The use of information and communication technologies (ICTs) became almost inevitable in 2019 due to the COVID-19 pandemic (Radesky, 2020). In this day and age, when there is an increased need for distance learning, we are beginning to realize the importance of developing tools to facilitate this learning. ICT can not only help with distance learning, but also enrich classroom teaching and make some of the more "boring" learning content more meaningful to students. Another tool, that can help with distance learning and enriching certain topics is citizen science (D'Alessio et al., 2021; von Konrat et al., 2018). When citizen science is introduced as a part of the learning curriculum, it often has a great effect on students' enjoyment and understanding of the scientific processes (von Konrat et al., 2018). Combined, these two tools come together as ICT-enhanced citizen science, which is increasingly being used for this purpose (Rodríguez-Loinaz et al., 2022; Salas & Barquero, 2021). Dickinson et al. (2012) define the concept of citizen science as systematized research conducted by non-professional researchers in collaboration with professional researchers, which may last for several years or even a lifetime or be limited to short-term collaboration. Collaboration between professional researchers and amateur researchers is often carried out in the form of projects, which can be divided into various levels, such as contributory, collaborative, or co-creative (Bonney et al., 2009). Around the world, there are thousands of amateur science projects, ranging from observing the weather to categorizing photos of galaxies by shape and color, to identifying whales in tourist photos by their flukes—and thus tracking their migratory movements (Happywhale, n.d.).

Various forms of amateur science help make science more accessible to the masses, encourage participants to independently educate themselves in various branches of science, and enable users to acquire useful skills (Aristeidou, Herodotou, Ballard, Higgins et al., 2021). Marjanovič Umek and Zupančič (2020) state that children's self-perception of academic competence is crucial for their motivation to participate in the activity and put in the effort required for the activity, even if they are not actually competent. Therefore, it is very important to include activities in the classroom that foster students' belief in their own competence. Phillips et al. (2018) note that amateur science projects, especially those that require multiple levels of engagement, can lead to a deep personal interest in the environment and science. Research has also shown that participants gain more confidence in their learning abilities by participating in amateur science projects than participants that do not (Hiller, 2012). However, a significant difference between participants' knowledge and the demands of the project can have a negative impact on confidence in students' learning abilities (Phillips et al., 2018).

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Citizen science is widely spread – this is indicated by a variety of projects and applications that can be found. However, an important question is, why one should try and include the activity early in the person's life? Hart (2008) explains that children need to actively participate in community projects so that they learn the responsibilities that come with their rights. However, it is important to involve them in a way that is beneficial to both themselves and the other participants. Hart uses the metaphor of the participation ladder, adapted from Sherry Arnstein's (1969) ladder of adult participation. He uses this ladder to explain the lowest three categories of participation—manipulation, decoration, and tokenism—all examples in which children are involved in projects only for the sake of external representation and not for the actual benefit of the students. This metaphor is only meant to be a starting point for self-reflection (Hart, 2008). When using the metaphor in this sense, it is necessary to be aware of the importance of involving children in citizen science projects so that they can learn about their rights and responsibilities and improve their knowledge and interest in the subject they are actively involved in.

ICT in Biology Education

There are several ICTs that not only replace or enhance the user experience, but also change the entire user experience in the biology classroom. One useful ICT for teaching biology is the digital biology key. Biology identification keys are very effective in improving students' knowledge of plant species names (Anđić et al., 2019; Laganis et al., 2017; Torkar, 2021). Thomas and Fellowes (2017) discovered that, even if there was no significant difference in obtaining species knowledge between using books and apps to identify species, mobile devices offered more opportunities for students to engage with the subject outside of the allocated teaching time due to their general portability and accessibility.

There are many applications on the internet that have been developed for various purposes. Google Lens makes it possible to photograph a subject and then perform an image search on the Google search engine to show related content. Applications such as PlantNet, LeafSnap, and PictureThis are meant for identifying plant species, and Rockd is designed for identifying rocks. There are also apps such as mySmartBlood, in which the user enters the results of blood tests and it then uses machine learning to make diagnoses from clinical cases (of course, this application does not replace a doctor's visit, but it is a great information tool).

iNaturalist

In this study, special attention has been paid to the iNaturalist application because the focus of the application is on collecting biodiversity data using a citizen science research approach. This is not the only application that does this, but it is the only application at this time, that allows the collection and identification of all living organisms and their tracks, not just plants or birds. The application allows users to communicate, share, and discuss observations and identifications. In this way, amateurs can also contribute to biology research because their recorded observations can be reviewed by the community of researchers and eventually incorporated into actual research. The application can indirectly help reduce "blindness to biodiversity" because users learn more about the world of living things around them through the application and as a result pay more attention to what is happening in nature (Boone & Basille, 2019; iNaturalist, n.d.-a). The application is growing in popularity. By September 2022, nearly 129,000,000 observations had been recorded, of which 54.54% were deemed worthy of research (iNaturalist, n.d.-b). At that point, the application had nearly six million registered users. Scott Loarie, co-director of the iNaturalist application, had already observed the use of data from the application in over 150 articles by 2018 (Irwin, 2018).

This study reviews articles that report on the educational outcomes of using iNaturalist in biology citizen science. To explore the possibilities of iNaturalist, the following research questions (RQs) were established:

RQ1: How often was iNaturalist used in the primary, secondary, and tertiary levels of education by March 2023?

RQ2: Which groups of organisms were covered in biology citizen science education using iNaturalist by March 2023?

RQ3: Which teaching and learning methods and approaches were applied while using iNaturalist in biology citizen science education by March 2023?

RQ4: What were the learning outcomes of using iNaturalist in biology citizen science education by March 2023?

Methodology

Research Design

A systematic literature review method was used to address the research questions. To conduct a systematic literature review, Preferred Reporting Items for Systematic Reviews (PRISMA) 2020 guidelines were followed (Figure 1).
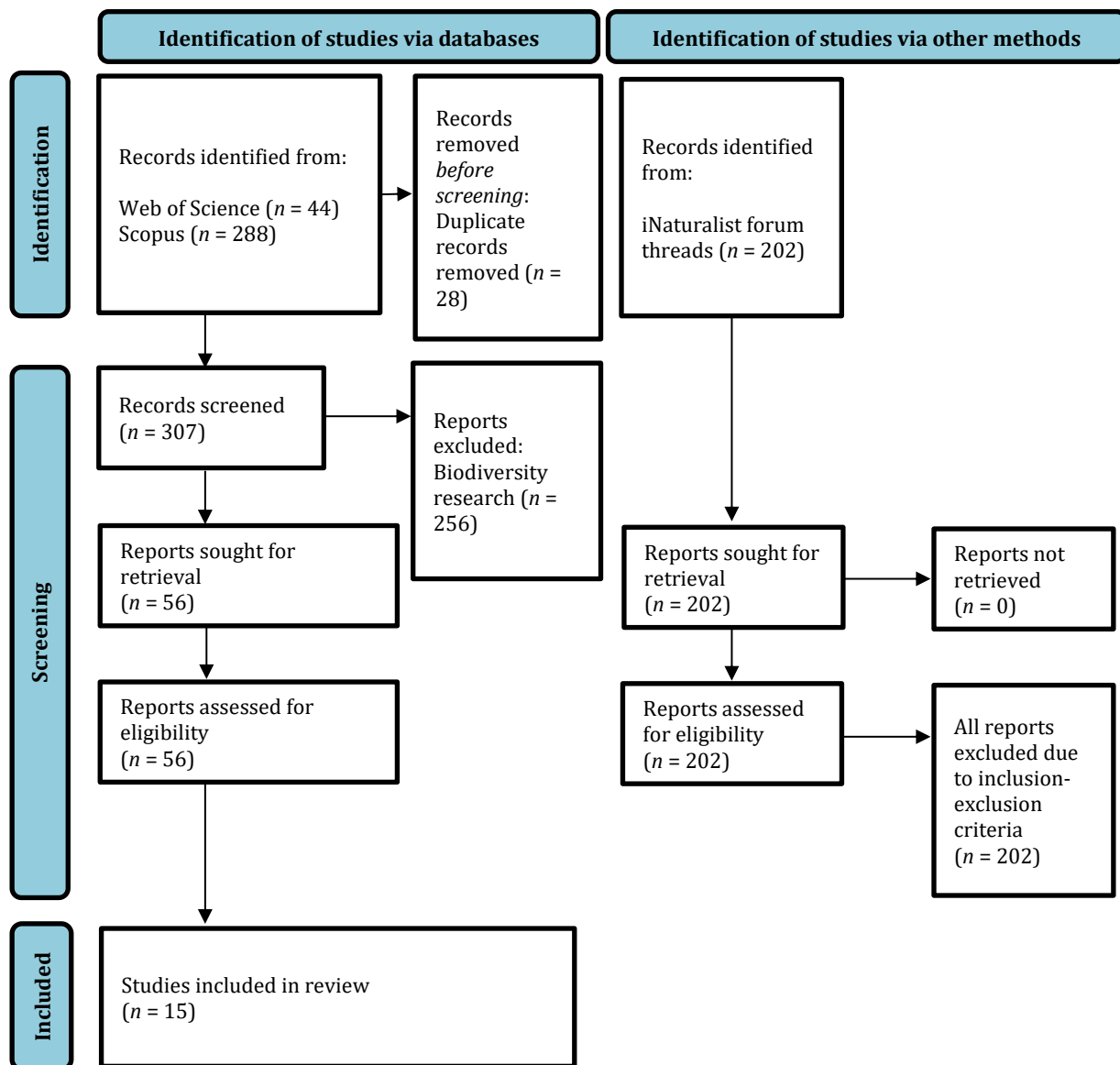
Figure 1. PRISMA 2020 Flow Diagram for New Systematic Reviews that Included Searches of Databases, Registers, and Other Sources.

The studies included in the review: Aristeidou, Herodotou, Ballard, Higgins, et al. (2021), Aristeidou, Herodotou, Ballard, Young et al. (2021), Boaventura et al. (2018), Echeverria et al. (2021), Gass et al. (2021), Gerhart et al. (2021), Harlin et al. (2018), Mech et al. (2022), Niemiller et al. (2021), Paradise and Bartkovich (2021), Pollock et al. (2015), Rokop et al. (2022), Smith et al. (2021), Unger et al. (2021), Young et al. (2021).

Sample and Data Collection

A systematic search of article databases, including Web of Science (WoS) and Scopus, was conducted from January 2023 to March 2023. As a preventive measure, to avoid articles being overlooked, an additional source of articles was used in the form of iNaturalist forum threads (iNaturalist Community Forum, 2019, 2021, 2023), where members of the forum (often authors themselves) can post citations of articles using iNaturalist in the search. The search strategy was based on the use of core terms related to the topic of the research: *iNaturalist* and *education*. We searched in all areas (we considered articles suitable if they contained the concepts we were looking for in all areas of the article). The search for scholarly articles posted on the iNaturalist forum was performed manually by extracting citations and checking them for suitability.

Data Analysis

After our initial search (using only the keywords *iNaturalist* and *education*), the total number of entries after removing duplicates (twenty-eight) was 332, of which forty-four were found on the Web of Science, 288 on Scopus, and 202 in the iNaturalist forum posts. The abstracts of the articles were reviewed for relevance: the articles selected had to relate specifically to teaching with iNaturalist and its impact on learning. Excluded were those articles that only drew data about

a specific organism from the application (e.g., a review of sightings of grey herons in Slovenia recorded in the iNaturalist application) or that only mentioned the role of education in biodiversity conservation. After the initial selection of articles based on abstracts (twenty-four articles in total), a more detailed review was conducted by two independent reviewers by reading the entire article. Any articles that did not meet our relevance criteria after reading the content were additionally excluded (e.g., poor use of English, or iNaturalist was mentioned but not used in teaching). The study also included one article that was not discovered through previous methods of identification, but as a citation in an article by Rokop et al. (2022).

Findings

In total, fifteen articles were identified in which the iNaturalist application was used in a biology education context (Table 1). In 2015, one article was published on the topic, none in 2016 and 2017, two in 2018, none in 2019 and 2020, ten in 2021, and, finally, two in 2022. iNaturalist was used four times at the primary level of biology education, six times at the secondary level, and ten times at the tertiary level (RQ1).

iNaturalist was designed to collect data on biodiversity using a citizen science research approach (Boone & Basille, 2019; iNaturalist, n.d.-a). The findings show that in the articles analyzed learners studied various groups of organisms. In many iNaturalist educational activities, groups of species to be identified were not specified. Instead, in some cases, the ecosystem was specified (e.g., intertidal rocky shores, local streams, and lakes). When groups were specified, most commonly they focused on plants and insects (RQ2).

iNaturalist was used in two main teaching and learning methods or approaches. The first one is a BioBlitz, which is defined as an event that focuses on finding and identifying as many species as possible in a specific area over a short period of time. However, we noticed that a BioBlitz in education was not used only for single events up to one day long (in three articles), but also as longitudinal activity (in five articles) lasting for a semester, a year, or even longer. It was also noticed that at these events participation is not limited to students, but is instead open to everyone interested. Furthermore, it is normally not assessed in the classes. In one study (Gass et al., 2021), expert naturalists helped the students with identification. Second, iNaturalist is part of a course (seven articles), or used as fieldwork, project work, or part of herbarium activity. Usually, only students and their teachers participate, and students are assessed for their activity. They are graded on the number of species observed and correctly identified, the quality of photos, and/or the number of research-grade records (RQ3).

The main learning objectives were to observe and identify species, and to learn about ecology, climate change, and biodiversity in general. The learning objectives were less focused on emphasizing the participatory approach in education, but this is an important educational outcome reported in the articles analyzed. Korfiatis and Petrou (2021) emphasized qualities that should characterize participation in educational activities: participation in decision-making, community cooperation, and interaction, development of team communication, and real action resulting in real outcomes. The findings show that students found the activities engaging, authentic, and exciting, and they often clearly indicated that they enjoyed them. Students tended to like the activities with iNaturalist because they often took place outdoors and because the activities gave them autonomy in the learning process, which motivated them to learn. Participation in the activities was a lot of fun, even though it was voluntary. After the activities, students learned more about biodiversity, stating that they had learned about species they did not know existed, and they showed increased interest in nature and a desire to identify more organisms. In most studies, students continued their participation by posting their observations in iNaturalist or expressing interest in further citizen science projects. No sex differences in the quality of observations submitted to iNaturalist were found in the articles studied. However, a difference in quality was found between age groups. Participants with a higher education tended to provide higher-quality observations. Observations provided by younger participants were nevertheless valuable contributions because iNaturalist hosts a robust community of naturalists that help with observations, even if they are not perfectly identified at the outset. The information contributed to the website was comparable to that contributed by the wider iNaturalist community and is therefore valuable to research in general. This knowledge of what makes a valuable contribution also helped increase student motivation to participate. BioBlitzes were used frequently and were very well received by the students. They often contributed to motivation and the amount of input added by students because they provide a competitive and collaborative aspect that makes data collection fun, which in turn increases motivation. This was frequently observed in most studies that a BioBlitz was used. iNaturalist was also frequently used as a complementary tool to traditional biology identification keys, as well as a complementary tool in creating herbaria, where its use increased students' confidence in their identifications (RQ4).

Table 1. Overview of Articles Found Across All Search Engines (W = Web of Science, S = Scopus)

Article	Source	Participants	Types of organisms	Activities	Purpose
Pollock et al. (2015)	W	Graduate students, faculty staff, undergraduate students, and others (friends, family, alumni; n = 108), all affiliated with graduate programs in ecology and evolution, microbiology, philosophy, and plant biology.	Not specified, but organisms had to be wild. The first event allowed pets and cultivated plants: food species at the market. Labeled species in zoological gardens, botanical gardens, and aquariums were not allowed.	Two (2014 and 2015, each seventy-six days long) BioBlitz activities. In the second year, iNaturalist was used. Participation was voluntary and noncredit for students.	The objective of this study was for students to learn more broadly about biodiversity and to make links between the researchers' work in ecology and evolution with their daily experiences. iNaturalist allowed for real-time record keeping of observed species, dates, and localities, as well as the inclusion of photos. It allowed them easy creation of personal species lists, and it allowed participants to receive ID assistance and feedback on their observations. The majority of participants reported species they did not know existed. They reported a high level of enjoyment with the competition and collaboration aspect of the activity. Most students reported improved knowledge of species, and nearly all continued to learn new species after the BioBlitz concluded.
Harlin et al. (2018)	Citation	Secondary school, undergraduate and graduate students, teachers, and professors. The number of students was not reported.	Not specified (focus more on plants, especially trees).	BioBlitz events twice a year. Longitudinal observation: established protocols for collecting information. iNaturalist was used as a method of collecting and storing data about species.	Students used the application to catalog observations and identify species (especially trees), to answer two research questions: How does elevation affect life? How will climate change affect the elevation distributions of species? Students were very excited to participate. They said they felt like scientists, they felt like they were actively contributing to climate and biodiversity research, and they also felt like they saved lots of time for scientists by collecting the research data.

Table 1. Continued

Article	Source	Participants	Types of organisms	Activities	Purpose
Boaventura et al. (2018)	W	More than three hundred primary school students plus in-service teachers.	Intertidal marine species	Students were first introduced to the topic by participating in an activity at the National Natural History Museum. Then the activity was carried out at the seashore, where students worked in groups of five and used a tablet to upload the data on iNaturalist.	Focusing on the causes and consequences of climate change in ecosystems of intertidal rocky shores, learning to identify marine species, and acquiring ICT skills to insert data into iNaturalist. Researchers tried to answer two questions: How did mobile digital technologies contribute to learning? What were the potentials and limitations while using mobile digital technologies in the research activities? Students demonstrated high digital skills while also providing valuable data for monitoring the coastal marine species distribution and understanding how climate change may affect biodiversity. Most of the images uploaded were high quality, but more than half of the species were wrongly identified. In-service teachers emphasized that iNaturalist is friendly to use, motivates students for learning, allows them to be autonomous in the learning process, and develops students' digital skills. Main observed some technological limitations, such as poor internet connections and tablets' screen brightness.
Unger et al. (2021).	S	Undergraduate students ($n = 82$) taking an introductory organismal biology course (first-year biology students).	Samples from a local stream and lake (with an emphasis on macroinvertebrates, amphibians, and fish) or forest (terrestrial insects and other arthropods and occasionally vertebrates, when encountered).	Using both iNaturalist and traditional dichotomous biology keys and field guides. First students identified the organisms using biology keys and field guides. One student per group took photos and uploaded observations using the iNaturalist application to see whether it could ID the organisms better or differently.	Students used iNaturalist to assist in identifying organisms alongside traditional paper-based dichotomous keys and field guides. They learned how to identify morphological characteristics of local species of animals and plants and learned to be more receptive to emerging technologies based on the effectiveness and simplicity of iNaturalist. The use of iNaturalist following traditional methods of identification confirmed most organisms and bolstered student confidence in their identifications. Students reported that they were more likely to use iNaturalist following the activity. Students had a harder time identifying aquatic organisms, compared to tree and leaf-litter organisms with the iNaturalist application.

Table 1. Continued

Article	Source	Participants	Types of organisms	Activities	Purpose
Smith et al. (2021)	S	Students (n = 209) from various majors at the College of Agriculture and Life Sciences, College of Natural Resources, College of Humanities and Social Sciences, College of Sciences, and College of Engineering.	Arthropods	The assignment was required and comprised 10% (in the second year 15%) of the final course grade. Students had to create an account on iNaturalist and post at least one observation of arthropods indoors. In the second year, students could choose whether to use Seek by iNaturalist or analyze bumblebee observations submitted to the iNaturalist database.	Researchers wanted to examine learning outcomes of students from various majors participating in citizen science experiences as part of a general education science course. Following citizen science experiences, students' interest in science increased significantly. Interest in nature, self-efficacy for environmental action, and self-efficacy for learning and doing science revealed modest, but not significant, gains. Non-majors tended to increase more than majors, and students in 2020 tended to increase more than students in 2019, with significant differences in changed scores for self-efficacy for environmental action and interest in science. In 2020 more students stated that they were likely to participate again, compared to the 2019 cohort. Students that chose the iNaturalist assignment rather than Seek saw overall larger increases in all four constructs, with a significantly higher changed score for interest in nature.

Table 1. Continued

Article	Source	Participants	Types of organisms	Activities	Purpose
Aristeidou, Herodotou, Ballard, Higgins et al. (2021)	W, S	Young volunteers (*n* = 249) ages 5 to 19.	Not specified	BioBlitz events organized by the Natural History Museum in Los Angeles and the California Academy of Sciences.	The researchers aimed to explore the extent to which young volunteers' contributions on iNaturalist are of potential scientific use to biodiversity research; to explore the verifiability and quality of young volunteers' observations overall and per iNaturalist's taxon category; to explore the relationships (if any) between participation behavior (proportion of active days and duration) and proportion of contributed research-grade quality observations; and to explore the relationships (if any) between background characteristics, including age and sex, with the proportion of research-grade observations contributed. Young volunteers' observations in the study were proportionally similar in data quality as the broader iNaturalist community, which consists primarily of adults. With the proportion and duration of active days on the platform, the research-grade ratio improved. There were no significant sex differences in data quality. There was a significant difference in the amount of observations reaching research-grade level between groups thirteen to fifteen years old and sixteen to nineteen years old. The latter had a greater amount of successful observations.

Table 1. Continued

Article	Source	Participants	Types of organisms	Activities	Purpose
Aristeidou, Herodotou, Ballard, Young et al. (2021)	W	Young volunteers (*n* = 183) ages 5 to 19.	Not specified	BioBlitz events organized by the Natural History Museum in Los Angeles and the California Academy of Sciences.	To explore young iNaturalist volunteers who participated in BioBlitzes and compare them to the broader iNaturalist population. They aimed to answer two research questions: 1) to what extent do young volunteers that participate in BioBlitzes contribute on iNaturalist, and what organisms do they predominantly focus on, and 2) how does young volunteers' participation behavior relate to their contribution? A small number of participating volunteers generated the majority of observations in iNaturalist. The majority of volunteers contributed only on one or two days. The authors concluded that onetime events in citizen science projects are not as effective as a systematic continuous approach.
Niemiller et al. (2021)	W, S	Secondary school, undergraduate and graduate students; number of students not reported.	Several projects were carried out in courses in biogeography, fundamentals of biology, herpetology, organismal biology, and principles of ecology, where students observed the biodiversity of selected groups of species according to the focus of the course.	Students received a grade for their iNaturalist work. The grade was predominantly evaluated based on student effort to complete the project, with an emphasis on the quality of observations and determinations.	The aim of the study was to document local biodiversity to foster students' respect and empathy for nature and organisms. Students (with few exceptions) enjoyed the project and expressed positive outcomes, enthusiastically reporting to researchers about their explorations.

Table 1. Continued

Article	Source	Participants	Types of organisms	Activities	Purpose
Echeverria et al. (2021)	W, S	Two groups of students (*n* = 122), age sixteen, enrolled in a biology course.	Plants, various trees, and shrubs	The biology lesson consisted of three sessions: a fifty-minute presentation of iNaturalist and protocol learning, five hours of fieldwork, including making a traditional herbarium (and optionally also digital), and fifty minutes of uploading observations, explanation, and evaluation of the work.	The aim of the study was to create traditional and digital herbaria, to use iNaturalist as a tool to make a digital herbarium and to record a photo and the scientific name of the species in situ. Half of the students voluntarily participated in making a digital herbarium with the help of iNaturalist. Students particularly liked that their data were merged with the data from academic institutions and later used in research. The second group of students enjoyed comparing their results with the data collected in the first group.
Gerhart et al. (2021)	W, S	Students in various undergraduate courses; number of students not reported.	Not specified	The 2019 cohort performed a BioBlitz event on the campus during regular class to practice using the iNaturalist application. Then the students participated in a Nature Challenge event, in which they were required to post at least twenty observations of wild organisms. Similarly, the 2020 cohort participated in the Nature Challenge event, but due to COVID-19 restrictions they individually collected observations of organisms. Cultivated plants were also allowed to be posted (as long as it was marked as such in the application).	The aim of the study was to explore the usefulness of iNaturalist in distance learning for undergraduate students of ecology during the COVID-19 pandemic by comparing two cohorts of students: one in 2019 and one in 2020, when COVID-19 restrictions were put in place. The remotely instructed field course in 2020 was less engaging for students than in person; however, students still responded positively. Students' engagement with and enjoyment of participatory science continued beyond the class project and became part of their regular activities.

Table 1. Continued

Article	Source	Participants	Types of organisms	Activities	Purpose
Gass et al. (2021)	S	Students (n = 631) from seven undergraduate courses in science and the arts.	Not specified.	A one-day BioBlitz event. Students were provided with field guides, handouts of common plant species in the area, binoculars, insect nets, magnifying glasses, and a light trap for the night session. An expert naturalist helped them with the identification.	The BioBlitz was an experiential education opportunity to build key skills in species identification in students, while also involving them directly with the research work through the collection of data for the BioBlitz and introducing them to the concept and practice of community science. The authors also strove to foster long-term engagement and advocacy for biodiversity stewardship on campus. The last objective was to introduce students to or reacquaint them with natural areas on campus and foster a positive sense of the place. The event provided students with a valuable hands-on learning experience due to the activity being held outside and not in a "traditional" classroom. They also referred to finding species they had never noticed before, and they liked the authentic learning activity provided for them. Students also noted that the iNaturalist application was part of what made the experience valuable due to its accessibility and ease of use.

Table 1. Continued

Article	Source	Participants	Types of organisms	Activities	Purpose
Paradise and Bartkovich (2021)	S	Biology and environmental studies students (*n* = 29) and one political science major enrolled in an entomology course.	Arthropods.	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 level, all others only to the family level, with documentation of resources used to identify specimens, including tracing the path to through the keys. They used BugGuide or iNaturalist for observations. For each species identified, students then downloaded a dataset of occurrences for it from the GBIF database to investigate species' range shifts.	The focus of the activity was to identify insects and upload them to the BugGuide or iNaturalist application, allowing students to make practical use of what they learned throughout their studies. The majority of students who decided to use iNaturalist strongly agreed that it was a resource that helped them identify the specimens observed. Almost two-thirds to three-quarters agreed that their understanding and appreciation of biodiversity was enhanced through the use of iNaturalist. The majority of students stated that they were likely to continue to collect insect images to upload to BugGuide or iNaturalist.

Table 1. Continued

Article	Source	Participants	Types of organisms	Activities	Purpose
Young et al. (2021)	W, S	Students from grade school to college; number of students not reported.	Not specified.	A multi-location activity, one-year project, with occasional short-term BioBlitz events (mostly one to three hours long, with one exception one semester long). For each location, a virtual plot was created. All these project were linked under one umbrella project to compare results.	The aim of this study was generation of species lists for comparison among nineteen participating schools and non-profit locations to draw conclusions about the ability of citizen science to contribute to biodiversity knowledge and inform scientific questions. Students' education level was the best predictor for the amounts of all types of data collected: as education level increased, the number of total and research-grade observations increased significantly. Education level had no effect on the number of introduced species observed. There was a significant influence of observers' education levels and number of observers on the percentage of research-grade observations of plants. The proportions of observations of plants at the site decreased as either the number of observers or education level increased. The same trend was also observed for bird observations: the number of bird observations increased with education level. The percentage of other taxa observations increased with the number of observers. BioBlitz events were performed at half of the sites, and the results showed a significant increase in total and research-grade observations as well as in the diversity of the species observed at a site.

Table 1. Continued

Article	Source	Participants	Types of organisms	Activities	Purpose
Rokop et al. (2022)	S	First year undergraduate students of management, psychology, computer science, nursing, and biology; number of students not reported.	Not specified	A BioBlitz event in the scope of a two-day orientation retreat for first year students. The event consisted of thirty minutes of training on the use of iNaturalist, followed by a field tutorial on photography techniques. This was then followed by a two-hour exploration of the area with a small set of supplies (to capture insects, etc.). At the end, students attended fifteen minutes of reflection and filling out the survey.	Researchers aimed to create an engaging citizen science experience for first-year students that did not have a prior background in fieldwork. To improve the activity, the citizen science project was repeated in three consecutive summers and years of students to generate insights that may improve future citizen science projects. More than 60% of students found the activity very engaging, and the majority indicated that they were interested in participating in a citizen science project. Students also believed their data were important to researchers. The students' self-reported level of engagement and interest showed that the activity described can excite students from various majors in a citizen science project.
Mech et al. (2022)	S	Undergraduate students from five universities enrolled in courses in forest protection, applied entomology, forest and shade tree entomology, and invertebrate zoology; number of students not reported.	Insects, occasionally fungi and plants.	Students had to collect observations as part of the assessment for the course. They had to collect a certain number of insect species (numbers and amount of credit received varied across courses and institutions). Extra credit was given for additional photos and for achieving research-grade level.	The aim of this study was to determine whether iNaturalist could be used to meet some of the learning objectives associated with traditional in-person entomology laboratory exercises, such as observation of insects, curiosity about insects and nature, and overall interest in entomology. Overall, the use of iNaturalist significantly increased students' agreement that social media platforms can be useful in teaching science. Basic science major students showed a significant jump in approval of such platforms. The use of iNaturalist did not appear to affect students' tendency to notice insects when outdoors. After using iNaturalist, students significantly increased their desire to identify insects. An increase in curiosity about insects was also observed. More than 60% of students also used the application again, after the class ended.

Discussion

Many articles used iNaturalist not with a focus on education, but rather as a method for obtaining biodiversity data. Despite the small number of articles that focused on biology education, an increasing trend can be observed over the years, though the sample size is quite small, so conclusions can't be drawn from this sample alone. This could indicate that the usefulness of the application for teaching biology may be recognized in the professional community, as well as the usefulness of the data obtained with the iNaturalist application, but to confirm this, further research is needed.

Research has shown that instructors benefit from using tools that facilitate the management and digital archiving of student-generated data (Hardy & Hardy, 2018), but it is not enough to introduce the application only in the classroom. For this reason, most articles include recommendations for using the application in schools to achieve an effective outcome from the activity. Some use a forty-five-minute introductory session (Echeverria et al., 2021; Niemiller et al., 2021; Unger et al., 2021) to prepare students for proper data collection and familiarize them with the application. It is useful to provide students with information, basic observational skills, and the skills to use iNaturalist, which will then enable them to use the application with greater ease, allowing them to focus on the biodiversity around them. iNaturalist already has some guidelines for observation recording protocols, but it is extremely important that the teachers leading the activity be familiar with iNaturalist to mitigate any issues that may arise—for example, understanding aspects of observations such as captive/cultivated tags and so on. Gerhart et al. (2021) recommended that participants already be familiar with the application and have recorded at least one observation in the application prior starting the activity. This could obviate the need for an introductory course because students are already familiar with using iNaturalist. However, course leaders should be alert to potential errors in which students might think they are doing the right thing but are wrong—for example, observing an ornamental tree and marking it as wild when it is growing outdoors. Gass et al. (2021) and Hernawati et al. (2020) also used experienced naturalists to guide participants and help them collect and identify specimens in their groups. This reduces the number of errors in observations because experienced naturalists would notice such errors and correct them if necessary. They also help in identifying the organisms observed, which in turn helps the students make more observations, develop observational skills, and not be overwhelmed by not knowing the names of the species observed. This is consistent with previous research as Sung et al. (2016) claim that one of the largest obstacles to implementing effective mobile learning programs is insufficient preparation of the teachers. Therefore, having experienced naturalists (or teachers, who are familiar with using iNaturalist) join in the activity could help bridge that gap. Physical biology keys were also often provided to participants to help with identification (Unger et al., 2021). This is also important because the use of dichotomous digital biology keys has been shown to be successful in improving students' knowledge of species (Laganis et al., 2017; Torkar, 2021). The use of keys could therefore help students become familiar with an organism they are trying to identify (Jacquemart et al., 2016). Subsequently using iNaturalist to store their observations and identify the organism using artificial intelligence, and later collaborating with the community, could help build their confidence in their ability to use dichotomous keys.

In the article by Harlin et al. (2018), students had to write a response to the prompt "Describe the forest you will be exploring." Before each hike, they had to write a description in their journal. In this way, the students activated their prior knowledge. By asking them what they thought they would find in the forest, a mental space was created in which they could get to know the things they found in the forest better. In the same article, the authors also explain that they limited the groups of pupils to their own square marked with string, which they then explored.

Rokop et al. (2022), Gass et al. (2021), Gerhart et al. (2021), Aristeidou, Herodotou, Ballard, Higgins et al. (2021), Aristeidou, Herodotou, Ballard, Young et al. (2021), Young et al. (2021), Harlin et al. (2018), and Pollock et al. (2015) used and recommended BioBlitz events because they promote experiential learning, provide a sense of place, and help create long-term commitment and advocacy for biodiversity conservation, while also contributing a great amount of observation to the iNaturalist dataset (Martínez-Sagarra et al., 2022). In these BioBlitz events, participants explore a specific geographical area alone or in groups during a specific time period and record their observations in the iNaturalist application. With iNaturalist's "projects," which are one of the application's functionalities, the users and organizers of such events have the opportunity to collect all the observations recorded in each area. These observations can then be filtered at will, statistically analyzed, and used for research or educational purposes to gain insights into either the flora and fauna of the area or the observation patterns and interests of their students. Such projects have been conducted, for example, by Rokop et al. (2022), Mech et al. (2022), Echeverria et al. (2021), Young et al. (2021), and Harlin et al. (2018). Gass et al. (2021) had a problem with more experienced students because they found the activity boring. The authors therefore suggest that, if the event is repeated, these students should be identified and used as managers, technical support for the application, or teaching assistants at the event. It should be noted that students of life sciences such as agricultural sciences, environmental sciences, and horticulture participated in this article. Because these students already have a basic interest in nature, it is assumed that they are more likely to become excited about an activity like a BioBlitz and approach it with interest and enthusiasm, which would probably be less the case with students from other disciplines. Nevertheless, the authors show that a BioBlitz and the use of the iNaturalist application is a useful way to increase interest in biodiversity and improve knowledge about the various species that live in the environment.

Education is a non-stop process, taking place during one's whole life, and it should consider the interests of learners by using a participatory approach. Participation is not just being actively involved in something, but rather a process of

sharing decisions that affect one's life and the life of the community (Hart, 2008). It refers to involvement in a collective decision-making process with a recognizable social and educational outcome (Kellett, 2009). It is also worth noting that some of the articles analyzed (Aristeidou, Herodotou, Ballard, Higgins et al., 2021; Aristeidou, Herodotou, Ballard, Young et al., 2021) used the participation metrics developed by Ponciano and Brasileiro (2014) to assess the outcomes of the educational intervention. The participation metrics are very useful in the quantitative analysis of users and their activities and can provide researchers with a lot of useful information, in addition to data on the species covered and the quality of the observations collected. The metrics are activity ratio, relative activity duration, and variation in periodicity. The activity ratio is defined as the proportion of days that the user was active and contributed at least one observation, relative to the total time from the first to last recorded observation at the site. The closer the ratio value is to 1, the more active the user is. The relative activity duration is defined as the proportion of the total number of days from the first to the last recorded observation on the website in relation to the number of days from the first recorded observation to the time of data collection. The closer the value of this proportion is to 1, the longer the user has stayed on the platform. The variation in periodicity is defined as the standard deviation of the number of days between each pair of observations. The closer the value is to 0, the less variable is the user's performance on the platform (Ponciano & Brasileiro, 2014).

Conclusions

To conclude, although research is already being carried out on using iNaturalist in education and the findings speak in favor of using the application in education, there is still much to be explored. Detailed educational guidelines for incorporating iNaturalist in education have not yet been formed; basic educational instructions for incorporating iNaturalist in a school curriculum are available on the iNaturalist website, and some authors (e.g., Harlin et al., 2018) provide general tips for specific educational activity. Such guidelines would be very beneficial for teachers and educators. Therefore, we suggest guidelines to use specifically with iNaturalist in education (see Recommendations chapter)

iNaturalist is not the only application that helps identify organisms. There are quite a few others: KEYtoNATURE, LeafSnap, PictureThis, Picturefish, BirdNET, and PlantNet. Each application has its advantages and disadvantages. Obviously, applications that focus on a specific group of organisms perform better than applications that focus on a more general group. However, no application combines so many aspects and functionalities, and focuses on such a wide range of organisms, as iNaturalist.

Recommendations

In this section, we suggest the guidelines to implement iNaturalist in a school context, as well as suggestions for further research. The educational guidelines were inspired by Harlin et al. (2018), who designed a roadmap for launching a citizen science program at school.

1. *Decide on the purpose of using iNaturalist in an educational context.* It can serve as a motivational tool for students to explore the school surroundings and learn about the biodiversity around it. If the activity is carried out periodically, future students can compare their findings with those of their peers. It is also possible to focus on a specific group of organisms if the lesson is focused on it. The activity could be designed by cooperating with local researchers, who can also accompany the teacher and students in the field and later show them how their data are used in research. In designing the activity, look at the Ten Principles of Citizen Science (Robinson et al., 2018), but, as Harlin et al. (2018) suggest, bear in mind that the bottom line as a teacher is to educate.

2. *Decide on creating the accounts.* Each student could have his or her own account, or a class account can be created, where the students receive login information. There are pros and cons to both: with a class account, it simplifies the startup process and overview of uploaded observations, but if students want to continue with their explorations, they have to create a new account, without having their previous work stored there. Another option might be using Seek by iNaturalist, which does not require an account, but observations are not stored in the iNaturalist database; it only provides live ID information. This might be more appropriate for younger students to help them learn and explore.

3. *Decide how long the activity will last.* The activity could be a one-time event, but a longer activity (lasting multiple days or even a full semester) will foster long-term engagement and a greater number of observations. A longer activity might even be better from a time perspective: teachers often do not have the time to dedicate multiple hours to such activities, and therefore a longer BioBlitz, for example, could help provide the time needed for dedication to observations.

4. *Leaders of the activity should download the application and learn to use it.* It is recommended that they have at least twenty to thirty uploaded observations to familiarize themselves with the process and the kinks in it, and also get to know at least some basic species that are commonly present in the activity area.

5. *Try to anticipate some possible problems in advance.* For example, if there are problems with internet access outdoors, it is possible to only take photos and upload them to the website later.

6. *Think about the equipment.* Not all students will have or will be able to bring their own smartphone devices. If the school has the option of borrowing tablets, that could be a solution. Another solution might be for students to work in

pairs or small groups, where only one member of a group has a device with iNaturalist and they jointly post observations.

7. *Other equipment for fieldwork.* Equipment such as nets for catching butterflies, magnifying glasses, fishing nets, and containers for collecting and observing organisms is recommended. They can enrich the learning experience.

8. *Keep in mind and learn about location privacy on iNaturalist.* Because the observations uploaded are publicly available, the locations also have public access. This might pose a security risk if students continue to use iNaturalist in their own free time and around their homes because their locations could be made publicly available. Therefore, it is essential that parents be included in the learning process and be informed about setting location information private, which is an option available on iNaturalist. This way, the data can be assigned as research-grade and are transferred to GBIF, the personal data are scrubbed, and the location cannot be connected to a specific user.

9. *An introductory class is recommended to educate students on using iNaturalist.* For example, the benefits of uploading multiple photos of a single organism (with different parts; for example, a flower from multiple angles, leaves, stalk, etc.), how to take clear photos, or avoiding multiple students making observations of the same organism. An important aspect is also taking photos of wild living organisms or their parts (even organisms in houses, if they are not meant to be there), and not human faces, animals in zoos, garden plants, and pets.

10. *After the activity*. Make sure to go through the uploaded observations with the students, to review and reflect on what they observed and what they learned, and to identify and correct possible errors that arose.

There is still a gap in knowledge about the educational benefits of using iNaturalist in the classroom. It has been proven that using iNaturalist in the classroom improves student attitudes towards biodiversity, but not much is known about whether species knowledge is better after using the application. Studies have been conducted looking at the difference between using traditional and digital biology keys, and some have even looked at the difference in knowledge acquired between using traditional keys and a species identification application, but there is a gap in research specifically using iNaturalist. We recommend that further research be conducted to test how many students continue to use iNaturalist after completing school activities, as well as longitudinal studies to see whether there is an effect on students' long-term behavior in relation to biodiversity and nature.

Another area of interest could also be the comparison of different teaching and learning approaches, for example, the differences between students participating in a traditional BioBlitz and a BioBlitz with iNaturalist. Further research could be conducted to test the use of digital dichotomous keys with iNaturalist – research by Anđić et al. (2021) shows the effectiveness of digital dichotomous keys over printed keys. However, there might be a problem when switching between multiple digital applications.

Limitations

The databases used for the literature review were WoS and Scopus. It is possible that an article could be found that would shed more light on the premise of this article by expanding the search area to include other databases. However, the two databases selected were chosen for their reputation in the research community. Another limitation of the research was that the iNaturalist application (and website) is an ongoing project in which both the application and the website are constantly being updated and improved. It is possible that some features that are in the application today were not available when some of the articles were written—for example, the computer vision model that the application uses to identify observations is constantly receiving updates and learning as new observations are uploaded. Therefore, an article published a few years ago criticizing the quality of the identifications made by the application could now be refuted when the model has been trained on a huge amount of data. This is just one example of possible limitations, and a suggestion for further research to expand usability where it may not have been found useful before.

Conflict of Interest

No conflicts of interest, financial or otherwise, are declared by the authors.

Authorship Contribution Statement

Rode and Torkar conceived and designed the study. Rode gathered the research articles. Rode and Torkar analyzed the data. Rode and Torkar interpreted the results of the experiments. Rode prepared the figures. Rode drafted the manuscript. Torkar edited and revised the manuscript. Rode and Torkar approved the final version of the manuscript.

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