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BRIEF REPORT

BotanizeR: A flexible R package with Shiny app to practice plant identification for online teaching and beyond

Patrick Weigelt[1,2] | Pierre Denelle[1] | Fabian Brambach[1] | Holger Kreft[1,3]

[1]Biodiversity, Macroecology & Biogeography, University of Göttingen, Göttingen, Germany

[2]Campus-Institut Data Science, University of Göttingen, Göttingen, Germany

[3]Centre of Biodiversity and Sustainable Land Use, University of Göttingen, Göttingen, Germany

Correspondence

Patrick Weigelt, Biodiversity, Macroecology & Biogeography, University of Göttingen, Göttingen, Germany.

Email: pweigel@uni-goettingen.de

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Societal Impact Statement

Confronting the ongoing biodiversity crisis and our incomplete taxonomic knowledge on the world's plants requires well-trained experts able to recognize and identify species. Although botanical training is an integral part of many university programs in biology, plant identification skills are becoming rare. The Covid-19 pandemic has challenged plant identification classes as many courses rely on hands-on practicing with plant material or guided excursions. Here, we present BotanizeR, a flexible online tool to make the wealth of digitally available but scattered information on plant characteristics accessible and allow users to practice plant identification. BotanizeR can assist in teaching plant knowledge in a playful way during times of online teaching and beyond and may help to increase the fascination of biology students and laypeople alike for plant diversity.

KEYWORDS

botany, Covid-19, floristics, online teaching, plant blindness, plant diversity, plant identification, Shiny application

1 | INTRODUCTION

Human impact is altering our planet at an unprecedented pace leading to the irreversible loss of biodiversity (Díaz et al., 2019; Johnson et al., 2017). A fundamental feature to tackle the loss of biodiversity is the ability to identify and recognize the species in a local community or region in the first place (Godfray et al., 2004). This is important not only for taxonomists but also for ecologists and conservation practitioners as well as the broader public: a better public knowledge about species can lead to a higher awareness of nature and threats and acceptance for conservation measures (Ardoin et al., 2020; Lindemann-Matthies & Bose, 2008). Despite the need for a profound understanding of the differences among species and their diagnostic morphological characteristics, the number of experts for certain taxonomic groups has been decreasing over the last decades (Pearson et al., 2011; Wheeler et al., 2004). Reasons for this are manifold and include a general focus towards molecular sciences and limited funding for botanical institutions including herbaria and botanical gardens (Godfray, 2002; Westwood et al., 2021). While vivid high-quality teaching in higher education is essential for training future experts and ecologists with a profound taxonomic and floristic understanding, the loss of lecturers with a background in floristics puts biodiversity research at risk.

Strikingly, botanical knowledge is at a particular high risk to vanish as plants tend to be underrepresented in biology curricula and students show a preference to learn about animals rather than plants (Jose et al., 2019; Wandersee & Schussler, 1999). This is linked to a general underappreciation of plants despite their enormous ecological and economic importance—a phenomenon called "plant blindness" (Wandersee & Schussler, 1999) or "plant awareness disparity" (Parsley, 2020). In addition to a lack of exposure to nature, this results in many students entering university programs with very limited plant identification skills. Mismatches between the number of local plant species and knowledge about these plants are most likely seen in regions like the Tropics, where high biodiversity coincides with an urgent need for conservation measures (Meyer et al., 2016). To overcome this dilemma, engaging with motivated students and nurturing their knowledge and enthusiasm about plant diversity is paramount (Webb et al., 2010). Besides an increased exposure to plants in the field, new technologies like interactive web applications can assist teaching of species identification skills and help to engage young people in biodiversity research and conservation (Orr et al., 2021; Pearson et al., 2011).

In recent decades, a wealth of online resources has massively increased the accessibility to botanical information for anyone with an internet connection. Such databases may be highly curated, covering specific plant taxa (e.g., The Gymnosperm Database, PALMweb, and Solanaceae Source), regional floras (e.g., the Online Atlas of the British and Irish Flora, Catálogo de plantas y líquenes de Colombia, and The Total Vascular Flora of Singapore Online), or growth forms (e.g., European Atlas of Forest Tree Species). Other databases may be global in scope (e.g., Plants of the World Online and World Flora Online) or part of larger efforts (e.g., Encyclopedia of Life) or general online encyclopedias (e.g., Wikipedia). While these web resources have become invaluable sources of information about plant species, information is scattered across resources, which vary hugely in scope and quality (König et al., 2019; Weigelt et al., 2020). Furthermore, they are often complex and very comprehensive and therefore not ideal for students, who typically have limited previous knowledge when starting to learn about plants (Buck et al., 2019). Similarly, smartphone applications like Pl@ntNet (Joly et al., 2016), Seek (inaturalist.org/pages/seek_app), or Flora Incognita (Rzanny et al., 2019) have become popular and widely used tools for identifying species and looking up species-level information. However, their usefulness for learning about species and differential characteristics may be limited as these applications can typically not be customized to cover only the content of a particular class in terms of the species and characters to be taught and identifications should be validated against conventional keys or reliable images (Jones, 2020). This calls for flexible tools that allow to easily combine user-defined information from various resources and present it in a didactically prepared and interactive way for teaching purposes. Multimedia tools that help students to learn botanical terms and train plant identification have been shown to significantly improve exam achievements (Jacquemart et al., 2016; Kirchoff et al., 2014). In addition to classical methods like field excursions and identification classes that introduce for example plant morphological characters and the use of dichotomous keys, an online application including repetitive and gamified aspects hence has the potential to positively affect student motivation and learning outcomes (Borsos, 2019; Su & Cheng, 2013, 2015).

The ongoing Covid-19-pandemic creates many additional challenges to botanical teaching and demands a lot from both lecturers and students. In many countries, lecturers prepare online content from recorded lectures to live tutorials and seminars. Students participate with limited direct interactions with fellow students and lecturers and need to demonstrate their learning progress online (Bao, 2020). This requires a high level of flexibility and inventiveness on the one side and adaptability and endurance on the other. Particularly, practical courses that involve the demonstration of, and working with, live material suffer from the online teaching model. Classic undergraduate botany and plant morphology classes or identification practicals are difficult to perform without a hands-on approach to show plant characteristics of a wide variety of species. While outdoor excursions in small groups might be feasible again soon as the Covid-19 pandemic comes to an end, indoor practicals for studying plant material and identifying species from specimens will likely have to be restricted to a minimum or held exclusively online for the time being, at least in some countries. Lecturers therefore need to strengthen active asynchronous learning outside of online classes and to combine synchronous online teaching and asynchronous learning effectively (Bao, 2020; Hrastinski, 2008). Existing online content and available textbooks rarely match perfectly with necessary course contents. Easy-to-use and modifiable online tools that may assist in the self-learning process are therefore urgently needed.

2 | BotanizeR

Here, we present BotanizeR, an online application designed to help botany students to learn to find and distinguish plant diagnostic characters, memorize plant species, and train identification skills. BotanizeR is based on a user-defined list of species and includes pictures, plant traits, habitat descriptions, and distribution information to help identify the species and learn about the species' morphology and ecology. It allows lecturers to define their own species lists of interest and to provide images and further useful information or use available content from selected botanical online resources (Figure 1), which makes it easy to use and highly flexible. Students can browse the species list and look at images showing different parts of a chosen plant species (e.g., habit, leaves, flowers, and fruits) and species descriptions. Additionally, a self-testing function in form of a quiz is implemented where images of a random species are shown and students have to guess the correct species thereby memorizing their names and characteristics.

Technically, BotanizeR is an R package (R Core Team, 2021) with accompanying Shiny application (Chang et al., 2020) which can be installed from GitHub (github.com/patrickweigelt/BotanizeR). This means BotanizeR is written in R, the most widely used programming environment for statistical computing and graphics in ecology (Lai et al., 2019), and can be used to build an interactive web application for practicing plant identification straight from R. It consists of a few main functions that collect images and species descriptions for a set of species from defined resources and the quiz itself. The *Quiz* and *Species* overview pages can be made available via a web page based on the package's interactive Shiny application (Figure 1). The Shiny application can be launched locally on a students' computer or on a web server to make it easily accessible to a broader audience. When launching it on a web server, BotanizeR can be accessed online via an URL, which can be integrated into institutions' teaching platforms, and species lists, online resources, descriptions, and pictures can be made available directly within the application by the lecturer. When using it

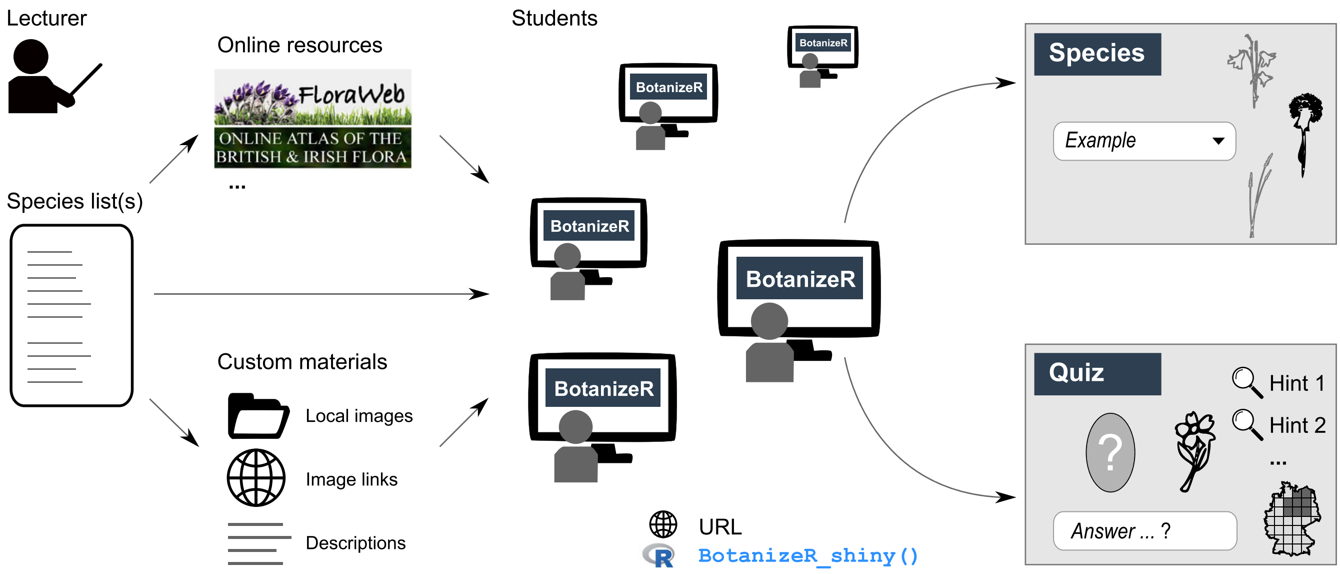

FIGURE 1 Visual overview of the functionality and variety of resources which can be made available via the BotanizeR Shiny application. The lecturer (upper left corner) defines a backbone species list, chooses from available online resources, and adds custom images and species descriptions to BotanizeR. The students (center) can then study those species and practice their identification and names via the *Quiz* and *Species* overview pages. They can individually save the species list, subset it, add personal information, and upload it again. The BotanizeR Shiny app can be run locally after installing the BotanizeR R package and running *BotanizeR_shiny()* in R, or it can be made available by the lecturer via a web server (URL). An example instance of BotanizeR for the floras of Britain, Ireland, and Germany is available at gift.uni-goettingen.de/shiny/BotanizeR/

locally, lecturers can provide a species list including additional species-specific descriptions (e.g., morphological characters) and images to the students for download. Both images and species information can then be loaded within the Shiny application in addition to the available online resources by the students and used to practice. This easy-to-use setup allows students to use the application without any R programming. In addition, the preparation steps from the lecturer only require basic R and computer skills. Relying on R, the most popular coding language in ecology (Lai et al., 2019), BotanizeR is widely accessible to people in academia. The code is fully open access, which makes it possible to adjust the package freely to meet personal preferences if needed. In contrast to existing multimedia tools for practicing plant identification (e.g., Jacquemart et al., 2016; Kirchoff et al., 2014), BotanizeR does not require any software (or data) to be installed on the students' side, and the content and appearance can be fully customized by the lecturer to perfectly meet the requirements of a given class (species, descriptions, images, and language). Tutorials on how to use and customize BotanizeR are available at: https://patrickweigelt.github.io/BotanizeR/articles/.

The Shiny application consists of two main pages (*Species* overview and *Quiz*) as well as *Setup* and *About* pages. While the *Species* overview presents all information provided for a species chosen from a drop-down menu, the *Quiz* shows pictures of a random species and requires the student to enter the correct scientific name (Figure 2). The application indicates if the attempt is correct. If the answer is wrong, the number of differing letters between the input and the actual name and whether the genus name is correct or not is displayed. The student can navigate through several images per species if available and can enable additional hints that ease the identification. These hints can—like the pictures—be provided by the lecturer or be drawn from the linked online databases. The quiz records the species shown and correct answers. This information is then used to provide summary statistics about the number of (in)correct answers and more importantly to update the sampling probabilities of the species. If enabled in the *Setup* page, species that have not been answered correctly become more and more likely to be shown. Students will hence be more frequently exposed to the plant species they struggle to identify. Also, students can download the species list including their scores after practicing and upload it in the next session to make use of the saved numbers of successes and failures, to add own hints and image links, or to practice a particular species subset.

The *Setup* page allows students to choose from species lists, pictures, and hints provided by the lecturer to use for the *Quiz* and *Species* overview pages. This is particularly useful if the overall content offered is large. For example, if the overall species list contains many species or a large taxonomic group, students can download the list, subset it, and upload only those species of a particular plant family to train them. Also, students can subset the chosen species list for only those species that are found in the Global Biodiversity Information Facility (GBIF) within a given buffer distance around user-defined geographic coordinates. Like this, students can choose to practice species occurring in, for example, their home region. If several image resources are provided, students can choose a particular online resource or local image folder to show (e.g., only vegetative characters) and which of the available descriptive text elements (e.g., family, habitat, floristic status, and morphological description) to

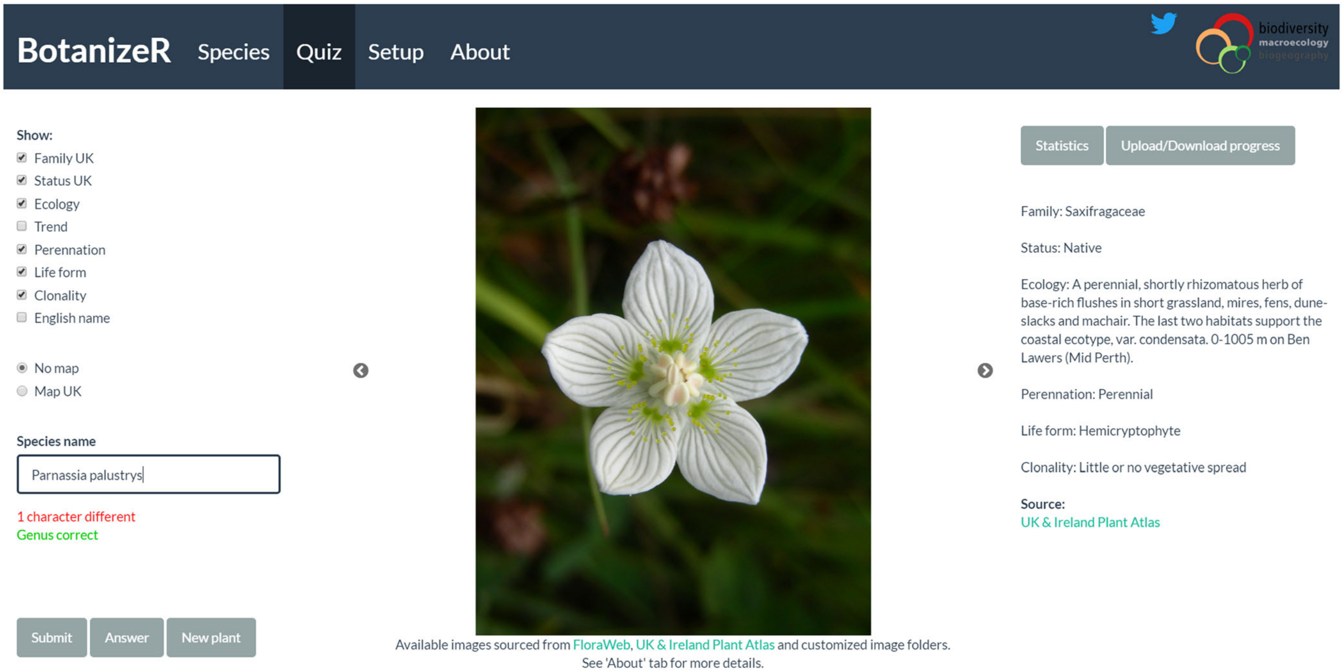

FIGURE 2 BotanizeR Shiny application showing the *Quiz* page. A picture of a random plant drawn from the user-defined species list (here *Parnassia palustris* L.) is shown together with additional hints the student can enable if needed. Once a species name is submitted, feedback about the correctness of the attempt is reported. The student can browse through several pictures if available. Here, the descriptive hints have been drawn from the *Online Atlas of the British and Irish Flora* (brc.ac.uk/plantatlas/). This example instance of BotanizeR for the floras of Britain, Ireland, and Germany is available at gift.uni-goettingen.de/shiny/BotanizeR/ (photo credit: Fabian Brambach)

use. The lecturer can choose whether to make the *Setup* page in the BotanizeR Shiny application available and which options to include or to allow predefined settings only.

To showcase the different use cases of BotanizeR, we present four separate instances of the Shiny application: one version of BotanizeR linked to large online resources can be found at gift.uni-goettingen.de/shiny/BotanizeR/. Here, users can study plants from two comprehensive lists of vascular plants from (1) Britain and Ireland and (2) Germany, which can be used entirely or as subsets of ~700 species representative of the Flora of Sussex County, South East England, or ~300 common species of the flora surrounding Göttingen, central Germany. The user can enable images and other content retrieved live from *FloraWeb* (a website about the flora of Germany; floraweb.de) and the *Online Atlas of the British and Irish Flora* (brc.ac.uk/plantatlas/) including the common species name in English or German, plant family, morphological descriptions, biogeographic and conservation status, habitat descriptions, and distribution maps based on Atlas Flora Europaea grid cells (Committee for Mapping the Flora of Europe, 1972–2018) and based on the New Atlas of the British and Irish Flora (Preston et al., 2002) (Figure 2). This instance of BotanizeR could, for example, be modified and used for classical plant identification classes across central Europe. To exemplify more customized use cases of BotanizeR, we also present two instances of the application we used in two of our own classes at the University of Göttingen, Germany, for teaching plant identification to forestry students in the academic years 2020 and 2021. One includes 128 common woody species in winter conditions occurring in Germany (gift.uni-goettingen.de/shiny/BotanizeR_winter/). Here, the *Setup* page is disabled and students need to identify the species solely by images of bark, twig, and bud characteristics. Another one includes 216 common forest species in summer conditions including herbs (gift.uni-goettingen.de/shiny/BotanizeR_summer/). Here, the *Setup* page is enabled allowing students to activate additional image resources and descriptions. Both instances were frequently used by the students of the two courses in addition to online and in-presence classes, which had to be carried out to a reduced extent due to Covid-19. Feedback was overall very positive as indicated by qualitative comments in the teaching evaluation (although we did not quantitatively evaluate impacts on learning outcome and exam scores).

As example from tropical regions, we present an instance of Botanizer offering two datasets from Indonesia (gift.uni-goettingen.de/shiny/BotanizeR_Indonesia/): 113 common wayside plant species of Jambi Province, Sumatra (Rembold et al., 2017), and 294 common tree species from Lore Lindu National Park, Sulawesi (Brambach et al., 2017). Both regions have highly diverse floras but few available resources about plants. Students of biology and forest sciences at the local universities of Jambi and Tadulako (Palu) thus face difficulties when attempting to become familiar with their respective local floras. To overcome this shortfall, BotanizeR for common wayside plants of Jambi is currently being used as a didactic tool in a trial run in cooperation with the Faculty of Teachers' Education of Jambi University, and we plan to establish a similar cooperation with Tadulako University on Sulawesi.

3 | CONCLUSIONS

BotanizeR is particularly helpful during times of online teaching but can also be efficiently used when universities go back to normal teaching modes. It will be a useful addition to regular classes for training one's memory of plant names and exam preparation. Of course, the tool cannot replace hands-on plant identification experience, but we are confident that it will help students to recognize and memorize plant species when used in addition to classical botanical teaching methods. Beyond classes, BotanizeR may help to prepare for field work in the scope of a thesis or research project about an unknown flora. Its flexible structure and open code allow for modifications and a variety of resources to be used. While the current links to *FloraWeb* and the *Online Atlas of the British and Irish Flora* already offer pictures, maps, and descriptions for more than 5000 plant species from Central and Western Europe, links to other online resources (like other regional floras or entire taxonomic groups) can be established. Thanks to its generic architecture, the package can also be adopted for taxa other than plants or expanded to retrieve information from the wealth of botanical online resources available worldwide. We hope that the interactive and responsive nature of BotanizeR motivates students and interested laypeople to practice diagnostic plant characteristics and plant identification and as such to contribute to the reduction of plant awareness disparity and the ongoing loss of taxonomic and floristic knowledge.

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CONFLICT OF INTEREST

The authors declare no competing interests.

AUTHOR CONTRIBUTIONS

PW and PD developed the BotanizeR R package and Shiny application. All authors contributed to assembling the example use cases and writing the manuscript.

DATA AVAILABILITY STATEMENT

Code and data of the BotanizeR R package and Shiny application are available at https://github.com/patrickweigelt/BotanizeR.

ORCID

Patrick Weigelt https://orcid.org/0000-0002-2485-3708
Pierre Denelle https://orcid.org/0000-0002-4729-3774
Fabian Brambach https://orcid.org/0000-0002-3203-2248
Holger Kreft https://orcid.org/0000-0003-4471-8236

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