CITIZEN SCIENCE:
THEORY AND PRACTICE

Creating Study-Specific Tools to Increase Community and Student Engagement

SPECIAL COLLECTION:
CITIZEN SCIENCE IN HIGHER EDUCATION

CASE STUDIES

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ABSTRACT

The Boulder Apple Tree Project (BATP) at the University of Colorado agglomerates ecological, historical, and genetic information regarding apple trees in Boulder County, Colorado with the assistance of community members, undergraduates, and researchers. Our goal is to map and measure historic apple trees in Boulder to find the varieties that were planted as part of Boulder's unique apple industry in the early 1900s. These trees are of interest to historians, horticulturalists, cider makers, and ecologists wishing to preserve heritage varieties and to better understand the ecology of urban apples. Combining the efforts of the campus community with the contributions of community members has allowed us to locate and measure more than 700 individual trees in the past four years, which are displayed in the interactive map showing locations and morphological measures of each tree. Harnessing this interest in local apple trees has allowed the project to provide educational opportunities to the community and undergraduates regarding the services that urban trees provide. Undergraduate computer science students built the interactive map to display tree locations and a mobile phone app designed for collecting and visualizing data in real time. These digital products will allow the broader population to engage in locally relevant research. This paper is a case study that focuses on curricular and extracurricular engagement of undergraduate students, application design, and the contributions of these efforts to the scientific community.

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INTRODUCTION

The clock is ticking in Boulder County, Colorado as the Boulder Apple Tree Project (BATP) races to find the remnant apple (*Malus* sp.) trees of the previous century. E. P. Sandsten and C. M. Tompkins censused 5,636 apple trees as part of their "Orchard Survey of the Northeastern District of Colorado" for the Agricultural Experiment Station of the Colorado Agricultural College (1922). Many of the trees planted were varieties that are no longer in commercial orchards today. Most of these trees have been lost as agricultural properties were subdivided to create housing for the growing population of the county, leaving only a small portion of the once expansive orchards behind. Apple trees have a lifespan of 80 to 120 years, and we are now at the end of that period for the trees that were initially counted. Preserving these once-abundant varieties in Boulder County and cultivating appreciation for their uniqueness requires exigency to find the trees before it is too late.

These trees are significant to community members, cider enthusiasts, and local food entrepreneurs who are passionate about preserving the genetic diversity of potential heirloom varieties tracked through this project. Community members have reported family stories and recipes involving particular historic trees; cider makers continuously share their enthusiasm about finding exciting heirloom varieties, and entrepreneurs express interest in utilizing locally sourced food in their products. Moreover, fruit gleaning occurs on open spaces, and there are efforts underway to produce regionally unique apple beverages. Given this local interest, educators at the University of Colorado, Boulder (CU Boulder) and Front Range Community College (FRCC) see the trees as an opportunity to teach undergraduate STEM students about the importance of urban forests and to expand knowledge about ecosystem services. Preserving the trees will benefit the local ecosystem (Spooner and Shoard 2016) while providing opportunities for local cider producers, horticulturalists, and educators.

The importance of conserving unique apples extends beyond Boulder County. As many commercial apple growers concentrate on a small number of varieties, limiting what is available on shelves, there has been an increased appetite for heirloom varieties among the general public (Veteto and Carlson 2014). Additionally, challenges such as climate change and disease make it critical for growers to have access to genetically diverse varieties to maintain a healthy standing crop (Volk et. al. 2015). Historic trees have thrived in challenging environments and have survived diseases that have impacted younger varieties (Magby et. al. 2019), indicating unique genetic resources that could benefit growers today. Increasing agrobiodiversity through locating and identifying once-common varieties that are now no longer part of modern orchards is paramount in preservation efforts (Reilley, Henk, and Volk 2009).

To preserve the genetic diversity and better understand apple tree contributions to local ecosystems, we need to map and identify the oldest remaining apple trees from the homesteading and orcharding era. Locating the trees helps us to ground our work in the local historic context by examining patterns in the old orcharding landscape. We can then target preservation efforts to focus on high-value historic trees, increasing the agrobiodiversity of the orcharding landscape while also working to expand ecosystems services provided by apple trees. Thus our driving question is: *How do we preserve historic trees as unique genetic and ecological resources while at the same time increasing interest, value, and appreciation for this resource among community members and undergraduates?* Our goal is to include as many apple explorers as possible in gathering, archiving, and disseminating data using undergraduate research experiences to expand the impact of our efforts.

Past research in citizen science has identified that involvement of the public in large-scale monitoring has been successful when public motivation to participate in scientific endeavors is high and availability of researchers is limited (Dickinson, Zuckerberg, and Bonter 2010; Tulloch et. al. 2013). The use of phone apps has been particularly effective in recruiting new community participants and improving data quality (Graham, Henderson, and Schloss 2011) by utilizing sensors that are embedded in most mobile phones (O'Grady et al. 2016). For example, projects in archaeology in California (Lercari and Jaffke 2020) and forest health monitoring in the United States (Crocker et al. 2020) found the utilization of apps highly effective because they speed the pace of data collection and increase the number of individuals monitoring remote spaces. Our project is similar to these studies in that it taps into local knowledge, utilizes GPS location capture technology via phone apps, allows for data collection and information display, and fosters a sense of community around collecting information to protect a local resource.

PROJECT GOALS AND SPECIFIC AIMS

The overarching two-fold goal of the BATP is to preserve the unique genetic and historic apple resources and bring community members, educators, students, and scientists together to collaborate, build community, and develop appreciation and value for apples. Under this umbrella, we aim

1. **To increase awareness, appreciation, and knowledge about apples and their ecosystem services within the community and especially among undergraduates.** Over the long-term, we anticipate this aim will contribute to the sustainability of preservation efforts by involving multiple generations of stakeholders and improve ecosystem services broadly by building interest in plants that can provide ecosystem services; and
2. **To engage students in authentic community-serving research and technology development in which they take action to understand, appreciate, and preserve these trees.** Students participating in community-serving research opportunities experience increased science competency and self-efficacy, motivation, and sense of belonging to scientific and local communities (reviewed in Corwin, Graham, and Dolan 2015; also see Brownell and Swaner 2010; Flanagan and Bundick 2011; Jones and Abes 2004; Pascarella and Terenzini 1991; Williams, Hall, and O'Connell 2021; Zaffini 2017). These outcomes give rise to other benefits including increased engagement and retention in science (Lobel and Cardamone 2016; Vitone et al. 2016). We aim to support student retention in STEM and continued scientific civic engagement through our project.

In this work, we describe our efforts to support the above aims through three specific objectives, all actively involving undergraduate researchers:

1. **We have mapped and gather data on historic apple trees throughout all known orchards regions within Boulder County.** With community and student partners we have collected (and continue to collect) historical, ecological, and genetic data that can be used to preserve unique apple trees across Boulder county. We also designed an interactive map to communicate this data.
2. **We have built and tested an interactive app to enable community members to actively participate in data collection.** The newly created mobile app was developed by undergraduates on the basis of our findings when gathering and mapping tree data. Through this process undergraduates worked intensively with our stakeholders to support app development and design. We hope this app will facilitate expansion of community participation and simplify data collection.
3. **We have partnered with other apple explorer groups to share information and data, and to promote preservation and appreciation.** Forging bonds between national apple groups enriches the knowledge and innovation of our group and enables us to expand our preservation efforts. We can contribute to national and international efforts by providing access to historic trees and locations via our interactive map.

This paper focuses on our efforts to achieve the three objectives listed above via productive multi-stakeholder collaborations. We describe a process in which community members contributed historic and cultural knowledge, and students and scientists contributed technical expertise to guide successful data collection and tool development during student-driven projects. Our results demonstrate how we have moved toward our broader aims.

METHODS AND RESULTS

INITIAL DATA COLLECTION AND APPLE BLITZ EVENTS

Data collection occurred from 2017 to 2020, and was collected by undergraduate students and community volunteers (***Table 1***). For each tree, we recorded the measurements that can be found in ***Table 2***. The majority of data collection took place in three large events called Apple Blitzes in which community members visited tree sites with student researchers to survey trees. Community members were recruited via the website and mailing list, which was distributed by our contacts at Widespread Malus and Boulder Open Space and Mountain Parks and also via the CU Museum of Natural History calendar and the CU community calendar of events. Student participants were recruited through the EBIO club, Restoration Ecology class, undergraduate student listserv, and by word of mouth. Researchers and graduate students at CU Boulder established protocols and obtained permits to collect data on public trees and permission from private property owners. Volunteers and undergraduate biology students also assisted in the data collection by measuring additional trees between Blitz events. After each Blitz, participants were provided with a qualitative survey to help us assess our impact and learn from participant experiences. Below we describe these efforts in chronological order.

Dr. Katharine Suding (KS) initiated collection in Fall 2017 with biology undergraduate students and a graduate student. Using information from several community groups (Widespread Malus, Boulder Mountain Parks and Open Space, Boulder County Extension), we located several apple trees. An article in the magazine *Coloradan* (Knoss 2018a,b), local newspaper articles (Niedringhaus 2018), and local television news highlighted the work of KS, Lisa Corwin (LC), and the students. This publicity helped interested community members locate our website, report tree locations and tree history, and volunteer for the Apple Blitz via Google Forms. With assistance from Addie and Jude

YEAR	# COMMUNITY VOLUNTEERS	# STUDENT LEADERS	# PRIVATE PROPERTY OWNERS	# PUBLIC SPACES	# TREES
2017	0	5	74	>10	199
2018	44	26	41	8	287
2019	20	11	40	6	128
2020	4	6	48	10	133
Totals	68	48	203	~34	747

Table 1 Summary of Apple Blitz participants, sites, and trees.

Note: Summary of community data collectors and undergraduate student apple explorers, property types, and number of trees sampled.

YEAR	2017	2018	2019	2020
Measurements	Location	Location	Location	Location
	Property type	Property type	Property type	Property type
	Tree height	Tree height	Tree height	Tree height
	Canopy width	Canopy width	Canopy width	Canopy width
	Trunk diameter	Trunk diameter	Trunk diameter	Trunk diameter
		Trunk rot	Trunk rot	Trunk rot
		Fire blight	Fire blight	Fire blight
		Fruit abundance	Fruit abundance	Fruit abundance
		Insect use	Insect use	Insect use
		Tree/fruit photos	Tree/fruit photos	Tree/fruit photos
		Fruit collection		
Data entry	Paper data sheets	Paper data sheets	Paper & EpiCollect	Paper & EpiCollect

Table 2 Summary of measurements by year and data entry method.

Schuenemeyer of the Montezuma Orchard Restoration Project (MORP) and Eric Johnson of Widespread Malus, KS and graduate researcher Deidre Jaeger (DJ) standardized a list of measurements for teams to collect (Supplemental File 1: Sample Data Collection Sheet). Based on community interest, we began to plan for our one-day data-gathering effort, the First Annual Boulder Apple Tree Blitz.

The first Blitz (2018) brought together community volunteers and undergraduate biology students. These participants indicated an interest in increasing their knowledge of the locations and types of local apples in response to the registration survey sent two weeks before the Blitz. Students received training to help them lead small groups of community members in surveying the apple trees. Additionally, students coordinated meeting locations and supplies, and trained volunteers as their team of community members carried out tree measurements. Teams recorded measurements with paper and pencil. In total, 287 trees were surveyed using measures listed in ***Table 2*** across public and private properties in Boulder County. Five apples per tree were collected for further lab analysis and morphological identification practice.

Post-Blitz data collation was time-intensive, requiring many hours of data entry, quality control checks, and organization of photographic data, which became expensive to the Project. As the crop yield in 2018 was unusually high, this was also the only year that we collected physical apple specimens. Processing, storage, and later disposal of apple specimens proved cost prohibitive and was not continued in subsequent years.

The Blitz 2019 included community volunteers (12 were previous Blitz volunteers) and student leaders who surveyed and mapped 128 apple trees, which were mostly found on public land. Due to the time-intensive nature of data collection in the first year, we decided to use a phone application for the second year of data collection. We considered and tested two apps. One was the CitSci app (*CitSci.org*), which was being developed at the same time as the first Blitz. We did not move forward with using this app because 1) it did not allow for obscuring tree latitude or longitude, which was necessary for privacy of landowners, and 2) it had several software bugs that we were concerned would discourage citizen science users. However, this app now hosts more than 1,000 citizen science projects and continues to grow, indicating that it is likely to have improved in utility over time. Instead, we selected EpiCollect, a cloud-based mobile data collection application that has been successfully used by citizen scientists in field data collection using their mobile phones (Aanensen et al. 2009; Gray and Ewers 2021). Author DJ had previous experience with the EpiCollect application and was therefore able to train participants in use. EpiCollect is free (which is important for limited budgets), easy to use, and provides the ability to download data in multiple formats, which allows for ease in data sharing with others. Especially useful is the ability to store images in individual cells of the spreadsheet instead of in a separate file, which was necessary when paper data entry was used. To use EpiCollect, users must pre-register with individuals in the BATP who hold a creator or manager role. The EpiCollect app is then downloaded to a user's personal device and they search for the project to begin data collection. Data collectors then follow the instructions in the app to measure and photograph different aspects of the apple tree. At the end of the data collection, the app prompts users to "Upload Survey," which is a mandatory step to provide the project with data from the app. After users upload the data, a creator or manager must merge the data from EpiCollect and add the information to the Interactive Map. Groups used both EpiCollect and paper data sheets as a back-up data collection method.

While EpiCollect was an improvement on paper data collection, we identified three barriers associated with its use: 1) The pre-registration process necessitated intensive planning prior to volunteers going into the field; 2) it could take several days to record participants pre-registration, which discouraged some users; and 3) users sometimes failed to complete the data upload, prompting us to either reach out to users or to engage in manual data entry using the back-up datasheets. We therefore resolved to create our own app for data collection in future efforts.

The 2020 Blitz was smaller because of the COVID-19 Pandemic. Community members used the website to submit locations of trees not yet surveyed by the BATP, contributing more than 75 new tree locations. To survey and map these trees, we recruited six pre-transfer undergraduate students from FRCC who then participated in a three-week summer bridge program, which constituted our 2020 Blitz. The bridge program was specifically designed for community college students to participate in professional development and to gain research skills before transferring to a four-year institution. Authors ADW, DJ, and LC collaborated with FRCC Instructors Maggie Prater, Laura Baumgartner, and Paige Littman to design and administer the program. Bridge students visited 133 trees across Boulder, Longmont, Salina, and Lyons. All data collection used EpiCollect and paper copies as back-up. Students reported feelings of accomplishment and development of self-efficacy on a post-survey and many echoed the feeling that, "the BATP is a great opportunity for students who are getting into their first research internship. I got to learn a bunch of valuable skills such as lab work, data gathering and entry, and experimental design."

THE APPLE BLITZ RESULTS

In total, 706 individual trees were mapped, measured, and tagged (41 trees from 2017 were revisited in subsequent years) (***Table 3***) between 2017 and 2020. In those years, 68 community members partnered with 48 undergraduate biology student leaders to collaboratively collect data (***Table 1***). The first Blitz year was by far the largest as we experienced a bumper apple crop in 2018, which attracted participants to the Blitz and made trees easy to identify. Community members evidenced excitement with quotes such as, "I really enjoyed being able to work hands-on with the trees, and learning about them via the ecological data and historical data was fascinating and a very enjoyable experience" from the post-Blitz survey. We expected the following year to be smaller due to the alternate fruit-bearing years of apple trees (Monselise and Goldschmidt 1982). Finally, 2020 had dual issues of pandemic and a late frost that impacted fruit set and resulted in a smaller Blitz effort. Despite the resulting decreasing trend in numbers of individuals participating in the Blitz, enthusiasm for the project remained high, as demonstrated by repeated

	BOULDER	LONGMONT	LYONS	SUMMARY
No. Trees 1922	1971	2925	740	5636
No. Trees Sampled 2017–2020*	580	91	35	706

Table 3 Apple trees then (1922) and now (2017–2020).

Note: Number of trees in Boulder, Longmont, and Lyons and the number of trees censused by Sandsten and Tompkins 1922.

participation of several community members in the Blitzes and consistent participation in the symposium (99 registrants in 2019 and 63 in 2020). One community volunteer noted in a post-Blitz survey from 2019, "I participated in the Blitz last year, and am excited to have the opportunity to do so again!"

These efforts helped create a data repository that will be useful to our key stakeholders: community members, cider enthusiasts, local food entrepreneurs, apple historians, students, and agricultural scientists. Tree surveys allowed us to quickly assess the health of the tree and estimate tree age. We were also able to compare trees growing in known orcharding locations based on historic images and maps. Data was also collected on the fruits: taste, color, shape, number of mature seeds, insect use, flavor analog, and in some cases Brix measures (1 gram of sucrose in 1 gram of solution) for sugar content. Apple explorers use this type of data to help identify the apple variety. These measures can be done with a minimal amount of tools and are relatively easy for novice citizen scientists to take.

The Apple Symposium was held in December 2019 and 2020 as a way to disseminate information learned during the Blitzes. The symposia assembled stakeholders for a three-hour event during which experts in cider production, apple genomics, and historic preservation gave presentations, and biology students from a course-based undergraduate research experience focused on the Boulder Apple Tree Project presented posters regarding research conducted on local apple trees (see our website for more information about this course). Students reflected on new knowledge gained in a post-symposium survey and mentioned that they enjoyed "learning about some of the cultivars of apple that are uncommon or rare like Colorado Orange" and "the many different uses [apples] ha[ve], especially in industry." Community members were encouraged to ask questions of the students regarding their research projects that involved apple trees. Students demonstrated the ability to navigate a professional conference setting through poster presentations; they presented sixteen posters in 2019 and nine posters in 2020, each representing a completed research project. Gathering with the community to share ongoing research in our region supported the campus and broader community relationship. One community participant explicitly mentioned that "programs like the symposium are great because they bring together students with community members of all ages and there are ways community can participate in a meaningful way."

The plight of heirloom apples is not unique to Boulder—it is a valuable "lost" resource across much of the American West (Magby et al. 2019). Apple growing regions previously extended along the front range from Wyoming to northern New Mexico (Carleton 2017). As the Project expands, we will need a way to involve apple explorers in data collection that does not require intensive training, specialized equipment, or any extra steps beyond visiting a tree with a tape measure and mobile phone. Our stakeholders indicated interest in having a way to visualize the data they helped to collect, through informal conversations during the Blitz, and a virtual location they can visit when collecting data far from CU Boulder. Given this, we resolved to develop an interactive website and a map that displays information about apple trees throughout our collection area, and an app to ease data collection.

We utilized the data from the initial three Blitz years to build an interactive map and phone app to assist in our data collection and community involvement efforts. In revising the protocols, we learned how to effectively communicate directions for taking the data of interest. We were able to determine which data was most useful to collect based on the feedback provided in surveys and conversations. Through using EpiCollect, we identified features of an app that would work for our project (e.g., collecting photos from within the app, setting units, mandatory fields) while finding others that constituted barriers (inability to register directly through the app, lack of direct access to the app through our website). We describe how these barriers informed our next steps in the section below. These learned lessons form the basis for a student-designed map and app to serve our community and to expand our reach.

PROJECT WEBSITE DEVELOPMENT AND INTERACTIVE MAP METHODS

We learned from our Blitz efforts that we needed several resources to improve community interaction. We sought to create an aesthetically appealing website that could maintain community interest, especially between events, and could be a central location where stakeholders from disparate locations could locate pertinent information. We pursued the creation of a map as a way to share the location, size, and identity of trees that stakeholders helped to survey.

We partnered with the science communication agency Impact Media Lab (*https://www.impactmedialab.com*) to build a website to serve these needs. Our website serves as an information hub for scientific and historical findings, a repository of protocols for tree measurements and preservation, and an organization space for community-facing events. It also provides insights into student and community involvement through the blog. The website was built in Squarespace (Brine template, version 7.0) with custom coding in CSS. The site is designed to be immersive, responsive, and easy to manage moving forward. The visual elements of the website are designed to build on the heritage aspects of the brand, including vintage illustrations, aged paper textures, and historic images of apple orchards in Colorado. The overall web experience is a feeling of old meets new, which echoes our goals of preservation and engagement of new generations with Colorado's historic apple resources. Our slogan, "Rediscovering Boulder's apple heritage, together," is featured prominently on the homepage. We use local search engine optimization (SEO) to promote engagement through organic web searches.

Our interactive map is featured on the first page of the website but serves as a stand-alone tool that allows users to view data and locations of the historic apples. To achieve a high-quality product (the map) and provide additional educational opportunities via the BATP, we engaged computer science undergraduates in the map's creation. The CU Boulder Department of Computer Science provides a year-long capstone project in which undergraduates create a product for a client in a group environment similar to what they will experience in the professional world. The Interactive Map was developed by a group of eight students who called themselves "Team Eden Crashers." These students participated in the 2019 Blitz to better understand how data was collected and to familiarize themselves with the information they would be presenting in the interactive map. Team Eden Crashers and ADW, the BATP project manager, agreed upon the following design principles: The map should 1) be easy and intuitive to navigate, 2) obscure locations of private property for privacy considerations, 3) provide searchable fields for finding locations, 4) include clearly marked and clickable apple icons, and 5) have cross-platform functionality. This resulted in an interactive map that has clickable elements that reveal information about the trees. Each tree is represented by an apple icon. Once clicked, information including the location, photographs, morphological measurements, and variety as determined by DNA fingerprinting (Volk and Henk 2016, Gross et al. 2018) is displayed. If there is a large concentration of apple trees in one area, a tree icon can be clicked to zoom in on the other apple icons. Team Eden Crashers utilized a wide variety of technologies and methods (***Table 4***) to develop the interactive map. Software development occurred on GitHub.

INTERACTIVE MAP AND BATP WEBSITE DEVELOPMENT RESULTS

The BATP website is an organization hub for the project. Eight events (Apple Blitz, Apple Symposium, Community History Day, and grafting workshops) have been organized and advertised through our community news and events tab. Community members and project boosters have made financial contributions through the giving page on the website. In addition to bringing community members to the project to contribute, the website provides information and resources to the community in a central location. More than 30 blog posts written by students have been published and emailed to the community through the BATP newsletter. The website contains links to our sampling protocols and information on the history and science behind the apples; these resources have been used by local educators to design curricula for community college, middle-school, and high-school students. Since the website launched in 2019, we have had more than 6,400 unique site visitors. In 2020 alone, we had visitors from more than 50 countries.

The interactive map can be found on the BATP website (*https://appletreeproject.org/map*) by clicking on a top-line banner on the main page that directs users to a dedicated page (***Figure 1***). A filter function allows users to show locations with certain varieties, tree size, number of hanging fruits (in 2018), and country of origin. A historic map overlay featuring a 1937 aerial survey of the front range can be applied as well (along with topographic and terrain features). The interactive map also resides on the website for the CU Museum of Natural History featuring the online exhibit for the project. Partnering with the museum allows for a potentially wider audience to explore the apples of our area and learn more about the associated history of apples in Boulder County, making tree data available to our stakeholders via multiple sites.

FRONT-END DEVELOPMENT TOOLS	BACK-END DEVELOPMENT TOOLS
AngularJS (structural framework for user interface creation that allows HTML, CSS, and JavaScripts to create web applications)	Amazon Web Services (AWS) hosts website
Leaflet (open-source JavaScript library for creating the map that enables use on mobile devices)	AWS Lamda (stores apple photos)
HTTP (Hypertext Transfer Protocol) requests are utilized to get apple data for rendering icons on the map and displaying tree information on photos	API (gateway manages endpoints)
Node.js (connects front end to back end)	Amazon RDS ([Relational Database Service] stores the database, and Amazon Cloud Formation is utilized for setting up API, Lambda and RDS)

Table 4 Summary of tools utilized by Team Eden Crashers for the development of the interactive map.

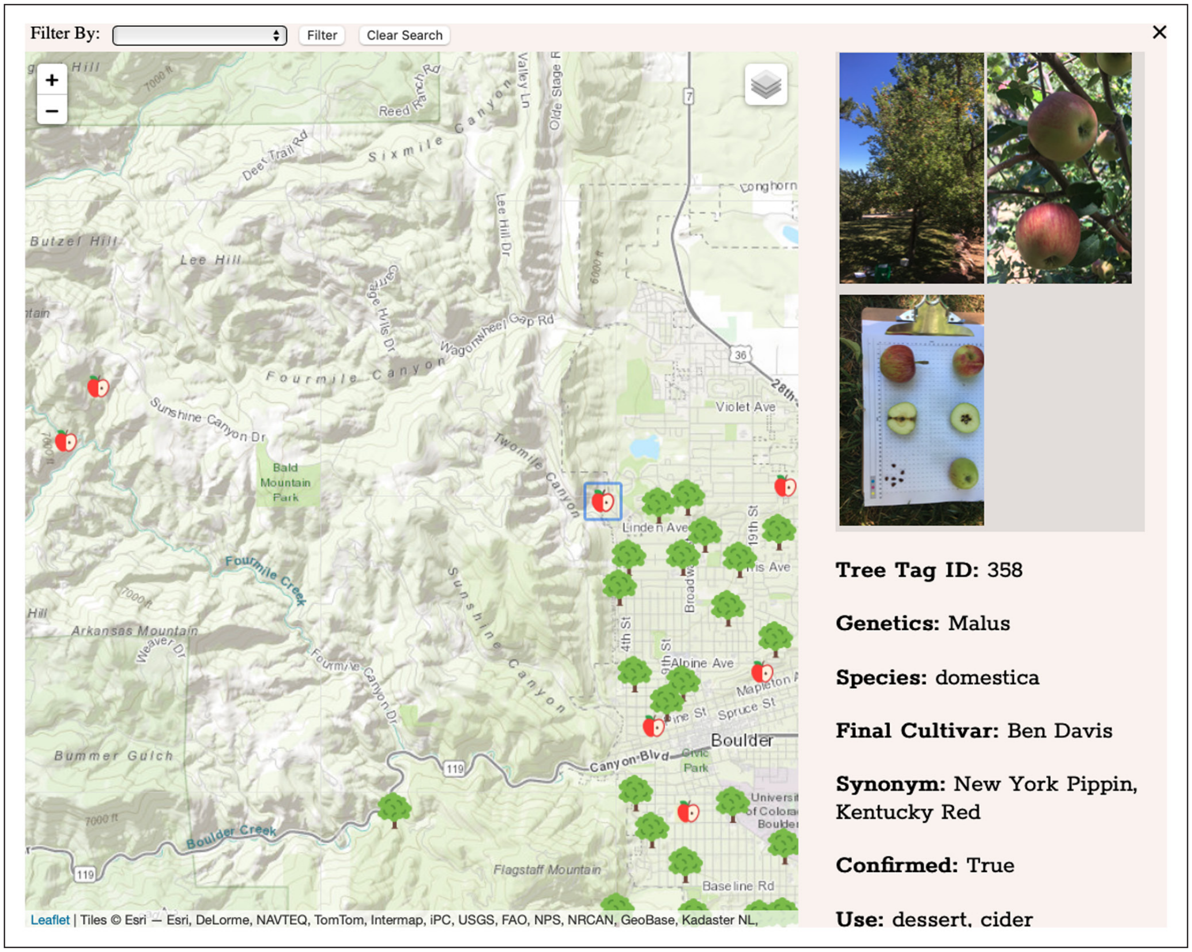

Figure 1 Interactive map display featuring an example tree. The apple icon shows the tree location on the map. Tree icons represent multiple entries in close proximity and will split into apple icons upon zooming in closer.

As the map was created with data from 2017 and 2018, we needed a way to import the EpiCollect data and provide users with the most up-to-date information. Thus, we set out to create a novel data collection app that can directly populate the interactive map with newly gathered data. This app will enable the project to be more sustainable as data entry is time-intensive and will allow project funds to be used for collecting data rather than completing back-end tasks.

MOBILE DATA COLLECTION APPLICATION DEVELOPMENT METHODS

After the BATP had a visually appealing map and website that invited exploration, our attention turned to streamlining our data collection process. We leveraged lessons we'd learned from our prior data collection experiences to build the app. For example, three big problems with paper data sheets are illegibility, incomplete datasheets, and lost data. Having a mobile phone app eliminates problems with illegibility, encourages complete measurements, and uploads data to one large spreadsheet, which decreases the amount of time researchers spend on data preparation for analysis. Using EpiCollect presents barriers associated with registration and data upload. Our app allows for instant registration without needing prior approval from a BATP member.

To streamline the data-collection-to-interactive-map process, we partnered with Apple Tree Team, a second group of computer science students enrolled in the year-long capstone class, to develop a novel data collection application that directly populates the interactive map with tree data. Apple Tree Team was composed of six students who utilized the following design principles: 1) registration of users for data checking and verification, 2) ease of use, 3) content prioritization in that the minimum number of measurements will be used to complete the data survey, 4) intuitive navigation, and 5) cross-platform functionality. Once again, Amazon Web Services (AWS) is used for hosting(*Table 5*).

The first page of the app displays the BATP logo and welcomes users to the app. We explain that users need not be expert field biologists to contribute to study measures

APP FRONT-END DEVELOPMENT TOOLS	APP BACK-END DEVELOPMENT TOOLS
Ionic framework (cross-platform launching and code storage)	Amazon Web Services (AWS) relational database server (RDS) to manage data
Vue libraries	

Table 5 Summary of tools utilized by Apple Tree Team for the development of the data collection app.

through the app. Users are then asked to create a login so that researchers can follow up with data collectors if needed and to protect against data spamming. The next screen provides a checklist for items that data collectors will need to measure the trees. Each measure appears in a drop-down format. Once all drop-down sections are complete, the users are guided to an upload page. Once data is uploaded, researchers are alerted to the presence of new measurements, data are checked for clarity, and then the information is forwarded to the interactive map. Team planning and general development tools were performed using GitHub.

MOBILE DATA COLLECTION APPLICATION DEVELOPMENT RESULTS

The mobile data collection app will be available for download June 2022 (a Beta version is available upon request from the authors) from both the Apple App Store and the Google Play Store, which can be accessed through the BATP website on mobile devices. This mobile app will allow us to partner with other apple explorer groups by contributing to national tree databases. App users have the opportunity to share their data with the Fruit RegisTREE of North America. The Fruit RegisTREE was developed by apple-exploring groups including Maine Organic Farmers and Gardeners Association, Montezuma Orchard Restoration Project, Widespread Malus, Temperate Orchard Conservancy, The Lost Apple Project, USDA Agricultural Genetic Resources Preservation Research, and Washington State University, and includes apple tree locations and data from across the country. A .csv file export made monthly and shared to the Fruit RegisTREE will allow for broader data use and cooperation among citizen science and research groups.

This application will be used in future Blitz events and in curriculum at other institutions including an ethnobotany course at the University of Northern Colorado, which used our data collection system to map and measure trees in the Greeley, CO. Using this app in future courses will allow students to see their tree data appear on the map in a timely manner. The creation of this app is also planned to facilitate the expansion of BATP efforts regionwide. We aim to expand data collection efforts to community colleges across the states of Colorado, New Mexico, and Wyoming in an effort to locate historic trees. The app expands and streamlines data collection that otherwise would require an unsustainable amount of data processing and coordination. Further, the app will facilitate the involvement of many more college students, community members, and scientists.

DISCUSSION

The BATP is a collaborative project that draws upon the talents, deep knowledge, and enthusiasm of all stakeholders. This unique combination of efforts and expertise aided in accomplishing our goals of starting to preserve the unique historic apples and building community, knowledge, and appreciation for these apples across multiple stakeholder groups. Below we report on four distinct outcomes of the efforts described above. We predict that these outcomes will serve to sustain and expand our efforts in years to come.

Our efforts have created a connection among stakeholders leading to a project that serves community interests and can sustainably continue. Community gatherings and large data collection efforts such as the Apple Blitz and the annual Apple Tree Symposium have been a wonderful way to include perspectives of diverse stakeholders. These events enabled engagement between communities that do not always have an opportunity to interact, specifically CU Boulder and FRCC students, local community members, and scientists. This enriches the project by facilitating the exchange of multiple ideas and elucidating priorities for stakeholders through discussion. The symposium in particular is an opportunity for introductory level undergraduates to gain experience presenting posters, to engage with other stakeholders, and to expand their professional network. This low-cost, university-hosted event also benefits community members who wish to learn more about cider making, preservation, and local history. Further, many community members report in post-event surveys that they enjoy feeling like a member of a research project that aims to protect their beloved apple trees. “The project is exciting to me because it’s an opportunity to learn about trees in Boulder and learn about their histories, both through sampling the trees themselves and speaking with the property owners. I had a great experience during the Apple Tree Blitz and I’d like to continue to help the project,” wrote one participant.

Beyond events, the ability to gather and share information through the website has become invaluable in developing our community, encouraging development of value and interest in heirloom apples, and ultimately promoting preservation efforts. Opportunities that have been organized and promoted via the website include grafting workshops, community history days, and a tree giveaway, all of which continue to build a solid foundation of stakeholder interest. The creation of the map and mobile app further extends our reach and serves community interests. These tools allow our stakeholders to look for trees of specific interest to them, connect with landscapes they have interest in studying, and get instant access to the data that serves their own purposes. Cider makers have used the map to find particular varieties. Researchers are using the map and app to assist in planning experimental designs to study ecosystem services. Residents use the map to navigate to particularly good areas to glean fruit. We have seen that the map and app facilitate some community members' desire to be stewards of particular trees because it allows them to be deeply involved in the preservation process. In addition, maintenance of the app is low cost and requires very little time commitment, an aspect we anticipate will continue to facilitate community members' engagement with this research for years to come.

The project has allowed for opportunities for project-based engagement of CU Boulder and FRCC students, increasing their skills across multiple disciplines. Three of the most impactful undergraduate experiences thus far are described above: the development of the interactive map and the mobile app via the two Computer Science Capstones and the summer bridge program for FRCC students. Experiential programs such as the summer bridge program allow the BATP to harness student interest in field research and provide training opportunities to help community college students succeed at research universities upon transfer. The majority of FRCC bridge students successfully transferred to four-year institutions and communicated feelings of increased comfort engaging in fieldwork, greater confidence in the transition to university life, and the development of research self-efficacy.

Students involved with BATP through the Computer Science capstone projects were able to engage with an area of study to which they otherwise would not have been exposed. All students from Team Eden Crashers graduated with employment secured (the Apple Tree Team are currently completing college).

The products from both of the computer science teams are currently facilitating additional opportunities for project-based engagement. The map has been used by introductory biology classes at CU Boulder and FRCC to further authentic research opportunities for students and to develop science skills. Using historic map overlays allows students to seek out past orchards to create and test hypotheses regarding the changing roles of apple trees in the local ecosystem. The map has also allowed students to seek out other apple trees that have not been previously identified but are in an area of known historic orchards.

Finally, we have been able to create scaffolding for other educational opportunities outside of the collegiate setting. Providing data collection opportunities through our website has allowed homeschooled students to participate in authentic research without having to be in a formal education program. Outreach with local summer camp groups has allowed the BATP to showcase the interactive map while teaching K–8 groups about the importance of tree measurements and geolocation. These experiences would not have been possible without the initial Blitz data, the creation of the interactive map, and the enthusiasm of community members.

These efforts have decreased the cost associated with the Project and increased sustainability. Support from community members and student involvement has allowed BATP to stretch thin budget resources much farther. We collected large amounts of data over three Blitz periods that would have taken much longer for an individual researcher to accomplish. Cultivating a motivated volunteer base that is constantly seeking out ways to be involved with the BATP has been a cornerstone of our project. We have history volunteers, tree stewards, volunteer field assistants, and tree reporters. Our stakeholders have donated time and money to help keep the BATP moving forward.

The development of the technological tools described also facilitates sustainability by streamlining the data collection process and requiring fewer personnel resources for training volunteers and data entry than prior methods. Utilizing the mobile app decreases the number of steps required to submit data to the project and increases the chances of participation by community members in the case of impromptu tree sightings. This added infrastructure means that research experts are no longer the gatekeepers to science participation.

The Project is contributing to national apple infrastructure and preservation efforts. The creation of this map and app has increased cooperation with apple exploring groups such as the Montezuma Orchard Restoration Project (MORP). MORP has worked with individuals who are passionate about the preservation of heritage apple varieties to create the Fruit RegisTREE of North America. MORP founders have acted as a consultant for the development of the app, which will contribute to the Fruit RegisTREE.

CONCLUSION

Engaging the talents and knowledge of the broader community in locating and measuring trees, utilizing student know-how to develop study-specific tools, and creating an environment for sharing information has made historic tree preservation broadly accessible and contributed to community learning and appreciation of apples. Our results demonstrate that our efforts to promote interest in local apple trees allow the Project to increase both community and undergraduate access to information and to opportunities to learn about the services urban trees provide. For many of our participants, these opportunities contribute to increased interest and enthusiasm. The creation of a mobile data collection application that populates the interactive map is a powerful way to include students, community members, and researchers in collaborative efforts to streamline data collection and communication. We anticipate that the use of the app and map, together, will support users in feeling part of a community working toward a common goal.

Community engagement was crucial in helping the project locate so many trees in the first few years of data collection. Continuing to foster community relationships with cider makers, orchardists, historians, and enthusiasts will allow the project to persist for years to come. Future goals for this project include uncovering the lineages of genetically unknown trees, preserving locally important though commercially unavailable apples through grafting, creating community orchards, expanding our mapping and communication efforts using the app, and expanding educational efforts across the region.

SUPPLEMENTARY FILE

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

- **Supplemental File 1.** Sample Data Collection Sheet. DOI: *https://doi.org/10.5334/cstp.420.s1*

ETHICS AND CONSENT

This work was reviewed by CU Boulder's IRB and found to be exempt (Protocol #s: 17-0540, 18-0410).

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COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

ADW is the project coordinator for the Boulder Apple Tree Project. DJ, IA, AS, KS, MP, LB, and PL and LC provided background research. KT contributed to the Project Website Development and Results. ADW, DJ, IA, AS, KT, LC, and KS contributed to drafting and editing of this manuscript.

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