The Beecology Project

Providing tools and information to promote citizen scientist participation in solving pollinator decline

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An Interdisciplinary Qualifying Project completed at
Worcester Polytechnic Institute
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Abstract

The Beecology Project 2017-2018 IQP team created tools and content to educate citizen scientists on the problem of native pollinator decline. The project team recorded tutorial videos showing how to use the bumblebee identification app, which allows citizen scientists to directly contribute bumblebee and plant information to a WPI database. A user friendly website interface was created to host educational information on pollinator decline and visualization tools for the bumblebee database. Since the database is in need of comprehensive, recent bumblebee data from citizen scientists, the team created a social media presence through Facebook, YouTube, and a brochure. The team held a webinar to demonstrate the Beecology application and our user centered tools through an online source.

Introduction

The Beecology Project was created to address the growing problem of native pollinator decline. This is a worldwide problem that will have lasting negative consequences if it is not addressed. Current data has shown that some native North American bumblebee species have declined in abundance by up to 96%, and in geographic range from 23-87% within the last 20 years(Cameron et al., 2011). The cause of these declines is currently unknown but habitat loss, climate change, invasive species, new pathogens, and pesticides are thought to be significant contributing factors. However, bumblebees are not the only important native pollinator species - many plant species depend solely on the pollination services of moths, butterflies, flies and beetles for reproduction. It is likely that many species from these pollinator groups are undergoing rapid population declines as well; however, we presently lack critical information needed to determine whether or not this is the case. This is a problem because according to the NRCS Wildlife Habitat Management Institute, almost 90% of plant species, and consequently the wildlife at other trophic levels that depend on them for food, shelter, and nesting sites, are animal-pollinated (Marks). The diversity of bumblebee and native pollinator species allows them to pollinate such a large range of plant species. But if enough native pollinators are all in decline, then ecosystem health and biodiversity around the world will suffer.

In order to address this problem, Dr. Robert Gegear started the 'New England Beecology Project' at WPI to study bumblebee species decline in Massachusetts. Bumblebees are ideal starting pollinators for studying native pollinator decline since they are easier for citizen scientists to identify than nocturnal moth species or other pollinator species. There is also considerable evidence correlating declining factors to bumblebee species decline, where this data is not available for other

pollinator groups. Even though many factors behind bumblebee decline are known, such as climate change, pesticide use, and loss of habitat, not enough current data is available to show how much each factor affects different bumblebee species. The Beecology Project aims to crowdsource collection of data about the needs of different bumblebee species and bumblebee pollination needs of native plant species through the Beecology App. This app allows citizen scientists to identify bumblebee and flower species in specific geographic areas based on a screenshot from a video and a guided ID process. This will help us to collect information about bumblebee/plant relationships in Massachusetts. As the Beecology Project expands, we hope to collect data on overwintering sites, bumblebee nesting sites, and information about other native pollinators. Once we understand how factors impact different pollinator species, we can develop conservation efforts to re-establish native pollinator diversity in our ecosystems.

Our IQP project surrounded the promotion and ease of use surrounding the Beecology Apps and website, as well as the education of the public on the need for bumblebee and native pollinator species diversity. We wanted to emphasize the need for diversity in plant species to support ecosystems as well, and we wanted to clear the misconception about native and managed pollinator decline, that bumblebee abundance was the only sign of a healthy environment, not species diversity. Since the project relied on citizen scientists to collect a large amount of data on bumblebee/flower relationships, it was essential that we informed large sections of the public about the issue to make it as easy as possible for users to input data to our database. Through the creation of tutorial videos for the Beecology App, and how to obtain the best photo for a screenshot, we made it easy for users to begin logging bumblebees with the app. Our outreach components and user friendly interfaces were also examined and critiqued by the public through a Beecology webinar that showcased all currently available tools in the Beecology project. With our social media presence

as a hub for announcing future tool development, this IQP project aimed to increase public awareness about bumblebee decline and to encourage more citizen scientists to contribute to the database.

Background

I. Pollinators, Ecosystem health, and Biodiversity

In order to understand the important role that pollinators play in maintaining function and diversity of ecosystems, it is critical to understand the co-dependent relationship between plants and pollinators.

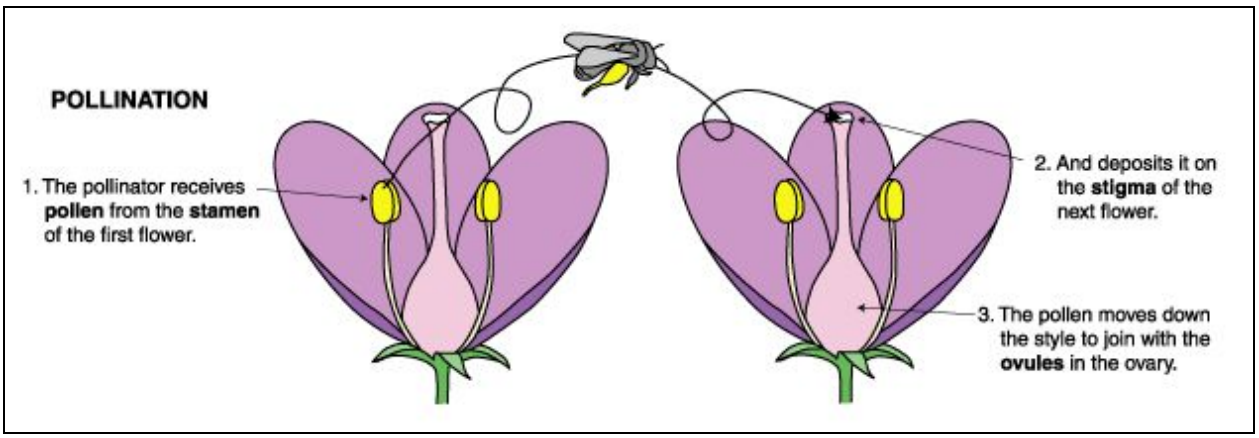


Fig. 1: Diagram representing the pollination process (Pollination clipart).

Almost 90% of flowering plant species require the assistance of an animal for reproduction. This process, referred to as pollination, involves the transfer of male gametes (pollen) to female gametes (ovules) for fertilization (Fig. 1). In turn, the pollinating animal uses the collected pollen (protein) and nectar (carbohydrate) as sources of food. Therefore, pollinators and plants are highly dependent on each other for survival and reproduction. Bumblebees, honeybees, bats, birds, moths, flies, and other major pollinator groups have developed a diverse array of morphological and behavioral traits that correspond to an equally diverse array of floral traits that have co-evolved over millions of years (Gilbert et al., 1980).

From the pollinator's perspective, the goal is to maximize the rate of food intake while foraging, and most pollinators have evolved a variety of cognitive functions (learning, memory, decision-making, problem solving) to help them associate or floral traits such as color (Reverté et al., 2016) and shape (Lázaro et al., 2008) with amount of food reward for a given plant species. Levels of relative competition for preferred flowers by other pollinators are also considered by different species when determining the best flower choice. To minimize stress of competition for the same resources, pollinators may be active during different times of the year, or they may collect pollen and nectar from different plant sources.

From the plant's perspective, the goal is to maximize reproductive success by attracting efficient pollinators and deterring less efficient ones that move pollen between flowers of different plant species thereby wasting male gametes and preventing receipt of conspecific pollen. In addition to producing greater rewards of nectar and pollen, some plants such as *Q. indica* have been observed changing color and scent throughout a season with each variation attracting a different set of pollinators (Yan et al., 2016). Some studies have even shown that production of small amounts of caffeine in nectar by *Coffea* and *Citrus* species improve honeybee retention of a learned floral scent (Wright et al., 2013). This manipulation of pollinator memory to remember the scent, color, shape, and reward of a specific flower will ensure that the pollinator will increase reproductive success of that flower species. Similarly to pollinators, blooms of flowers in different times of the season also allow for coexistence of multiple species in the same geographic area.

Pollinator-plant interactions directly impact a number of ecological services through their maintenance of stable population dynamics and community structure. Fibers, spices, and medicines production for human use is readily maintained by strong pollinator-plant relationships. Perhaps most importantly, pollinator-plant interactions play a keystone role in terrestrial ecosystems,

meaning that they have a positive impact on diversity at other trophic levels (e.g. seed eating birds/small mammals and the predators that consume them) and thus biodiversity and ecosystem health.

II. Bumblebee Biology

For this project, we focused specifically on bumblebees due to their ease of identification and their role in pollination of local ecosystems. Bumblebees have a variety of physical and behavioral traits that increase their efficiency during pollination. Bumblebees have corbiculae which are rows of long, strong hairs on the flattened tibial segment of the hind leg (Moisset and Buchmann). By mixing saliva or nectar into these pockets of pollen, it can be more efficiently carried and distributed than if it remained loosely packed as they are in the scope of other bee species. Since bumblebees have hair over their heads, thoraxes, and abdomens, their coats are extremely efficient at transferring pollen between flowers thereby conferring reproductive benefits to native plants.

Bumblebees also play an important role in an agricultural context due to their ability to "buzz pollinate" flowers, a behavioral trait not found in their close non-native cousin the honeybee. Buzz pollination is accomplished through the vibration of flight muscles while biting the stamens (male reproductive organ) of flowers, which makes them especially efficient in pollination of soft fruits such as tomatoes and berries (Bumblebees for Pollination). However, the importance of bumblebees as crop pollinators is relatively small compared to the $15 billion contribution of honeybees to the agronomy (USDA Releases Results).

There are approximately 50 known species of bumblebees native to North America, and 11 of them are native to Massachusetts, each of which has a unique relationship with native flowering plants across its geographic range. Although all bumblebee species have an annual cycle, these cycles

will differ by species (Fig. 2). Bumblebee queens will hibernate in overwintering sites until the warmer spring weather provides flower blooms for queens to utilize when they wake up. They will collect nectar and pollen while looking for a suitable nest site, which will have access to a large enough amount of flower resources. The colony will grow after the queen lays the first round of worker eggs , and those workers will continue the queen's initial task of nectar and pollen collection throughout the summer. It is at this time of cycle that most bumblebees are visible and active, and greater amounts of resources result in larger colony populations during this time. In the fall, the colony will produce new queens that will mate with males and become the next generation of queens that hibernate underground while the rest of the colony dies with the decreasing temperature (Fig. 2)(Smith) . With different

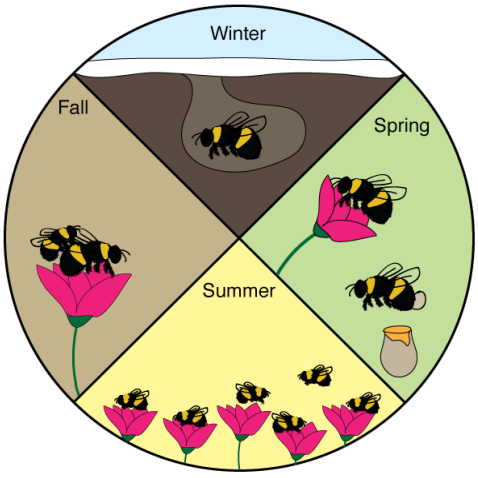


Figure 2: Bumblebee life cycle shows maintenance of native bumblebee populations as they interact with flowers in the environment (Blakely, 2015).

bumblebee and plant species relying on each other at different times throughout the season, disruptions to this the complex web of pollinator and plant relationships makes ecosystems with less diversity of bumblebee and plant populations even more vulnerable to decline.

A shift in phenology or a decrease in population size any stage of the cycle therefore has consequences for the structure and diversity of flowering plant communities in that area. Too great

of a shift or population change creates a bottom-up trophic cascade of population decline throughout food webs that rely on those flowers.

III. Causes of Decline

Many bumblebee species are experiencing unprecedented declines in abundance throughout their native ranges. Although the cause of these declines is currently unknown, contributing factors are thought to be habitat loss, industrial agriculture pressure, climate change, pathogens, invasive species, and use of certain pesticides. Current records on distribution of bumblebee species from the United States Department of Agriculture found that 46 species of bumblebees are found in North America, and 11 species of bumblebees were historically found in Massachusetts (Notestine, 2010).

Recent field observations from ecologists collected from 2015 to 2017 found that only 5-6 of these eleven species are still prevalent in the state (Fig. 3). Additionally, while historical observations between 1900-1990 show comparable relative abundance for 5-6 bumblebee species, only 3 bumblebee species have significant relative abundance at low and high elevations (Fig. 3).

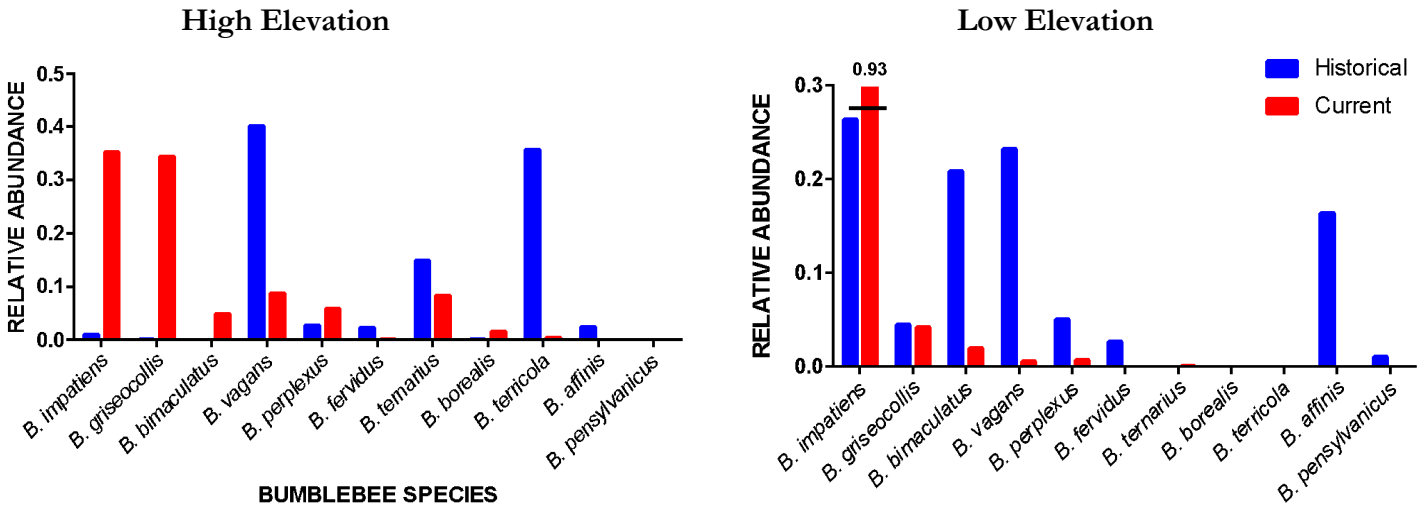


Fig. 3: Historical and current bumblebee population abundance by species in Massachusetts. Populations at high elevations above 1000 ft (left) and low elevations from 0-1000 ft (right) ((Gegear, 2018 [powerpoint]) unpublished data, historical data courtesy of Yale Peabody Museum of Natural History).

Rapid expansion of the agriculture industry has both reduced available physical space for bumblebee habitats and reduced air and water quality in nearby regions(Foley et al., 2005). While bee populations are observed in urban areas, the reduction in air quality and lack of larger foraging space still greatly decreases population density. Disruptions to flower populations as a result of increased agricultural land and suburban development can also decrease bumblebee population density of species that rely on greater rewards from those flowers.

Climate change has a detrimental effect on bumblebee populations as warmer climates disrupt cycles of flower blooming and bumblebee life cycles. One study noted that while a warmer climate may increase the duration of flower bloom seasons, this will also increase the number of days there will be poor flower resource availability leading to a shortage in food (Florida State University, 2017). The situation may be worse for bumblebees if their season begins earlier in the year since hibernating queens may not have enough nearby flowers for pollen and nectar to pick a suitable nest site. Changes in temperature from warm to cold throughout early spring may even kill off bumblebee populations that require the sustained warmer temperature to survive.

Honeybee and bumblebee interactions are inevitable in crossed population areas, and since honeybees may be susceptible to diseases that can infect bumblebees, they could spread foreign pathogens to the native bumblebees. Studies have shown that infection is possible between honeybees and bumblebees for DWV (deformed wing virus) and *Nosema ceranae* (a fungus that affects bumblebees); both of these pathogens are lethal for honeybees and bumblebees. Since there is a greater demand for field grown agricultural products, honeybees are used in more widespread areas that may have been originally inhabited by bumblebee species, increasing the interaction between these species. Less species diversity in bumblebees for an area could magnify the effect of

pathogens on bumblebees since effective pathogens would have an easier time spreading throughout one species with less genetic diversity than multiple species.

Consequences of competition have also arisen from increased contact between managed honeybee and native bumblebee populations. In areas where flower populations are relatively less diverse, it has been noted that adding honeybees limited the success of native bumblebee populations due to subdivisions of nectar and pollen resources (Florida State University, 2017). Additional competition between native plants and invasive species of plants may increase the rate of unsuccessful pollen transfer, resulting in lower seed counts between generations and less food to sustain native pollinator populations.

While pesticides are not always lethal to bumblebees outright, use of pesticides has been observed to affect bee behavior and memory. Most studies have focused on the impact of pesticides on industrialized honeybees, showing an increased susceptibility to viral pathogens, decrease in foraging efficiency, and death of colonies over time(Evans et al., 2009). The pesticide residues on affected bees appear to be transferable to nearby colonies, resulting in a greater range of infection than the chemically treated region alone. It is thought that the effects are similar for bumblebee species(Geib et al., 2015). One study showed that exposure to field amounts of the popular neonicotinoid pesticides led to decreased bumblebee colony growth, foraging, and queen production when compared to untreated colonies(Whitehorn et al., 2012). While an impaired memory may not be lethal in concentrations commonly used, the behavioral change may result in a decline of bumblebee colonies and an overall decrease in bumblebee biodiversity that will negatively impact local ecosystems.

Some data has indicated that factors affecting bumblebee decline do not uniformly affect all species. A study performed in California showed that extinction factors appeared to affect

large-bodied bees to a greater degree. Incidentally, these bees also appeared to interact with a greater range of flora species(Larsen et al.) . However, similar studies note that such conclusions are again hindered by incomplete population data(Cameron et al., 2011). Without first building this foundation of data, it would be difficult to create conservation plans of action against pollinator decline. This is harder to accomplish due to the largely incomplete data on population distribution of bumblebee species(Brown et al., 2009). If data can be collected about which bumblebee species correlate to specific flora species, and which areas have lower amounts of biodiversity in plant and bumblebee species, conservation efforts can move forward based on supporting data.

IV. The Beecology Project

The Beecology Project was started by Dr. Robert Gegear of WPI, and is made of up an interdisciplinary team of educators, computer scientists, biologists, and bioinformaticians. It was established to address the problem of native pollinator diversity decline through collection of recent ecological data for pollinators corresponding to plant species, visualization of that data, and education of the public on the importance of native pollinator diversity. Bumblebees were chosen as the initial native pollinator for this project due to their easily identifiable features, and conclusive data supporting their decline. Though the location and distribution of bumblebee species in Massachusetts is important to monitor, the collection of ecological preferences, such as floral choices, overlayed with geographic data is more important to this project, since hypotheses about the impact of specific declining factors on specific bumblebee species can be suggested.

We aim to fill in the gaps of knowledge about bumblebee and plant populations by crowdsourcing collection of this data to citizen scientists. The Beecology App, developed by two

previous MQP teams (Olivia, 2017), allows any citizen scientist to progress through a guided ID process to identify bumblebee and flower species in an area from a video. By increasing the participation in the project to include areas starting across Massachusetts, we hope to collect a current, comprehensive set of bumblebee species ecological preferences and distributions along with plant diversity. Overwintering sites and bumblebee nest locations will also be important markers to keep track of different bumblebee population success, although these metrics are much harder to monitor due to the difficulty of identifying bumblebee nests and overwintering sites.

Considering the consequences of bumblebee species decline, many projects across the world have been cataloging bumblebee species and floral correlations. The Xerces Society for invertebrate conservation coordinates bumblebee, butterfly, and other pollinator conservation efforts such as increasing the amount of suitable habitat to support multiple species, or giving educational seminars to farmers about the importance of native pollinators (Xerces Society's). Bumble Bee Watch incorporates citizen science in the collection of bumblebee and flower information and shows visualization tools to see distribution of bumblebee species across the United States (Colla and Hatfield, 2018). Citizen scientist projects such as the Bumble Bee Watch program or BeeSpotter at the University of Illinois also allow citizen scientists to submit photos and ID their own bumblebee species, which is verified by bumblebee experts associated with the project(Colla and Hatfield, 2018),(Berenbaum et al., 2017). The Beecology Project has citizen scientist/professional interactions, visualization tools, and conservation effort goals similar to these projects above with a few important distinctions. The Beecology Application allows a user to take a video and screenshot their photo all within the application. Emphasis on flower and bumblebee behavior with each submission is also rewarded since the project is looking to visualize bumblebee ecological needs, not just species distributions. Additionally, the project aims to expand to more native pollinator species and a wider

variety of visualization tools to truly understand the impact of declining factors on many kinds of pollinators.

The data collected by citizen scientists will be interpreted via visualization tools showing different metrics such as distribution of bumblebees by species, regions of Massachusetts by biodiversity, plant distribution and diversity, and overlays of other various metrics. Additionally, the database will be populated with historical data in order to show changes in population distribution between current data, and historical data from 1900-1990. Visualization tools will help ecologists to identify patterns based on bumblebee species preferences of flowers, current flower distribution, and anthropomorphic factors.

The culmination of the Beecology Project lies in the evidence it can provide to support conservation efforts to maintain or promote bumblebee species diversity. A common public understanding of the important roles these native pollinators play in the sustainability of our local ecosystems will help to ensure support and participation in conservation efforts. In order to create this understanding, misconceptions about pollinator decline need to be addressed, and user friendly resources need to be available for users to provide training and answer questions. The Beecology website, visualization demonstrations, tutorial videos, and a promotional platform needed to be developed as resources for the user. With an Android Application and a database for bumblebee logs already in place, the overall goal of our IQP project was to develop, implement, and promote these resources.

Project Goals

I. Goal 1. Create and host a live Webinar on the Beecology Project

To accomplish the first goal we developed a live webinar that we hosted in February. We started by narrowing down the most important aspects to put into the webinar. From there we created a set of scripts and over several practice webinar sessions we refined our scripts. We created a prezi, a more visually appealing version of a slideshow, to accompany the webinar as well. This is the primary visual aid we created but there was also a bumblebee model for the application demonstration among other things covered in the Methodology section.

The webinar covers all the goals mentioned, public awareness, outreach, and tutorial videos, but also includes additional details such as the tools for visualizing the database and taking questions from our audience at the end. Promoted through a Facebook event the Webinar took place live at 12pm on February 24th and was recorded to be added to the collection of videos, subsection I in our methodology section covers all of the details of the creation, execution, and feedback received from the Webinar.

II. Goal 2. Create Beecologist Tutorial Videos

The team saw a need for a collection of instructional videos to help the users learn to use the existing bumblebee identification application and provide more detail on the history and goals that the project aims to accomplish. Any of the information that would normally be presented during a demonstration of the app would be reiterated here for reference, and to reach any groups that cannot attend a live session.

In order to teach the public about the application and how to properly identify bumblebees there was need for the creation of tutorial videos. Additionally, to do this in a way that could also be hosted on the website being developed. The tutorials will be hosted on YouTube and Facebook platforms for easy access to those who need them. and linked to a video library on the site for those who need help, more in Methodology subsection II. This required scripts and background visual aids that are also covered in the Methodology section.

III. Goal 3. Design of the Beecology Website

The goal of the Beecology website would be to provide the central location for all aspects of the Beecology Project. The site will host the download to the mobile application, visualization tools linked to the database, and a web browser friendly version of the application and database visualization/modeling. Additional tools to boost recruitment to the project will also be hosted through the website, such as gamification and possible giveaways. An FAQ would also be provided on the website as an additional avenue for answering common user questions that come up in live demonstrations of the app and visualization tools.

The main page is for hosting any and all content related to the beecology project such as updates, downloading the mobile application, hosting tools for the database, and any other number of things as it can be updated by any future team. The hosted content can be updated at anytime and encompasses all aspects of the project, providing tabs to navigate through news, the app, social media, helpful information, contact information, and a custom user profile that may be connected via Facebook.

In Methodology subsection III.A there is detail on the website created over the two summer terms and issues we ran into there, from there to achieve our goal we began to develop a series of templates for the team that took over the design of the site.

IV. Goal 4. Design a Beecology Informational Brochure and Social Media Platform

The brochure consists of six panels each with a different focus on the project. The first is the title page and the important aspect is the subheading "Help us protect our local pollinators" which fits the goal of outreach. The second tells about the project and how to get involved, the third shows a user as part of our projects schema. The next panel is about the issues affecting pollinator decline and other general bumblebee information. The backside has two more panels; the first is the difference between what is and is not a bumblebee, the second is a short test for the user to take to give a quick evaluation of how their garden favors bumblebee diversity.

The brochure that gives a summary of the issues we are trying to convey along with other useful information on bumblebees, for more information check the Public Awareness section titled Brochure.

In order to distribute information, about any aspect of the project, we would also need a social media platform on Facebook and YouTube. Facebook would be the primary means of contacting the public and hearing feedback about the app and tools, since people can directly message the Facebook page administrators. Facebook would also foster communication throughout the community of Beecologists. Each of these requirements in the Beecology Project for a website, tutorial videos, and a social media platform would outline the goals for our Beecology IQP project.

Methods and Results

I. Webinar

Hosting Software

The Beecology: Bee the Change Webinar was set up as the main method of outreach to engage with the public. The setup for the webinar was screensharing of the Prezi presentation, Beecology Model, and mobile app demonstration through the Zoom software. Prezi is a dynamic powerpoint presentation software that has unique slide transitions we believed would be more engaging for participants to view. Zoom is a web meeting platform for users to share information and video feeds in real time. Participants went into the zoom.us/join link and used a specific 9-digit code to access the Zoom Beecology Webinar location. While participants are usually able to use microphones in Zoom, we used the administrative privileges to mute their microphones so that the presentation would not be interrupted. Instead, we directed question submissions to the built-in chat in Zoom software; this meant that attendees could submit questions to us throughout the presentation as they thought of them. The exception to this was Dr. Robert Gegear, as his microphone was un-muted during the questions portion of the presentation; as the advisor of the project and as a knowledgeable source for information on the project, he was able to help field questions from participants. Zoom was chosen as the webinar platform because it had the capacity to host up to 100 webinar participants, it had a built in chatting function, and it had the option to specify a meeting code to easily share a particular event with accounts that do not have other participant names as contacts.

Presentation Layout and Section Details

The layout of the Prezi presentation followed the following format:

1. Introduce the problem facing native bumblebees in Massachusetts and pollinator decline in general.
2. Describe basic bumblebee biology, and plant pollinator relationships.
3. Point out known causes of bumblebee decline and the Beecology project as a solution, emphasizing how citizen scientists would be involved.
4. Demonstrate the android application.
5. Show database visualization tool prototypes and bumblebee modelling resources.
6. Discuss the platform for future technology updates and future directions for the project
7. Direct participants to fill out a survey on the webinar, and address any lingering questions.

This format of presentation was found to be the most effective way to present this information based on the presentations Dr. Gegear would give in-person, so visuals and the Prezi were modified to suit this style [Appendix E].

From the bumblebee background to the listing of factors behind bumblebee decline, there were several points we planned to address. The evidence showing bumblebee decline at low and high elevations was meant to clear up any misconceptions that bumblebee species were not in decline in Massachusetts. We wanted to show that bumblebees were part of a larger group of native pollinators across the world, but that we did not have clear data about the decline of other native pollinators, even though factors that impacted bumblebees almost certainly have some impact on other pollinators. We wanted to show the distinction between native and managed pollinator

decline, and we wanted to show that the lack of data about the effect each factor has on each species of bumblebee is what was inhibiting conservation efforts.

A demo of the mobile android app was performed to show first time users how to navigate the app, and cover the nuances of bumblebee identification and proper imaging. This demo was performed using AirDroid screen sharing on an android 7.1 device. The logging options on the main screen were explained, noting that video capture is preferred as this compensates for human error through the use of built in editing tools. A model of a bumblebee was created from a papercraft diagram (Fig. 4).

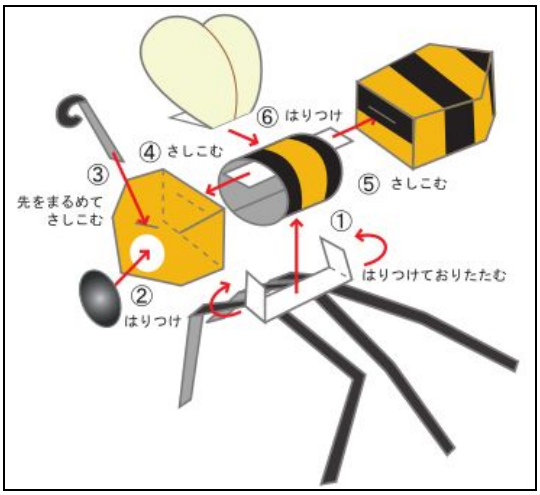


Fig. 4: Papercraft bumblebee model used during the Android app demonstration of the webinar.

This bee was manipulated by a team member above a model flower to exemplify real world conditions when logging. Users were instructed to follow the movements of the bee and keep an overhead angle to allow clear view of head, thorax, and abdomen color patterns. Afterword, in-app editing tools were used to cut down and produce a clear shot from the footage. How to use the slow, zoom, and pan tools was detailed.

Users were walked through the guided identification process with this still shot. The papercraft bee model was modified to resemble *Bombus impatiens*; the process would proceed as though this were the real species. The importance of additional data, such as current date, location,

and flower details was emphasized. This data would be necessary for forming associations between bumblebee species and floral species.

From here, the webinar proceeded to show a visualization (provided by Xiaojun Wang) of how data submitted through the mobile app was used to identify species distribution and diversity of bumblebees in Massachusetts. A map was displayed with grids of species data spread throughout the region.

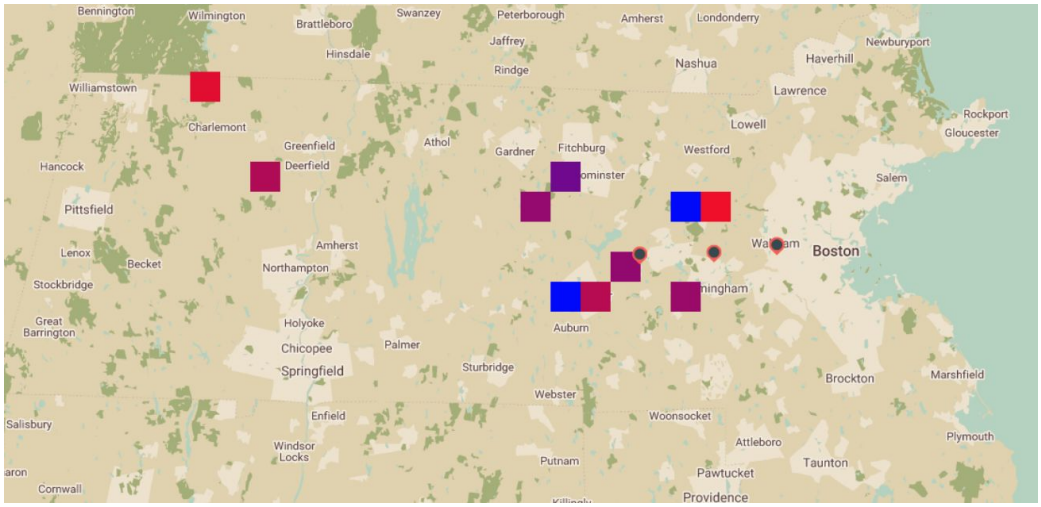


Fig. 5: Massachusetts bumblebee diversity data

Each region was given a relative color on a gradient, with dark blue representing low diversity, and red representing high diversity. With current data as of 2017 being sparse for the state, it was emphasized that this visualization did not necessarily indicate a drop in diversity, but simply a lack of data.

As an additional tool for Beecologists, we demonstrated a bumblebee population simulation created in NetLogo (Moon and Yu, 2017)(Blakely, 2015) that could show the effects of pesticides on bumblebee populations over several generations (Fig 6). The model is based on bumblebee biology. Virtual bumblebees move from flower to flower collecting both nectar and pollen while carrying pollen to each flower they visit. Bumblebees also have a programmed memory of flowers that give

the greatest reward that is informed based on the types of flowers they visit during each foraging trip.

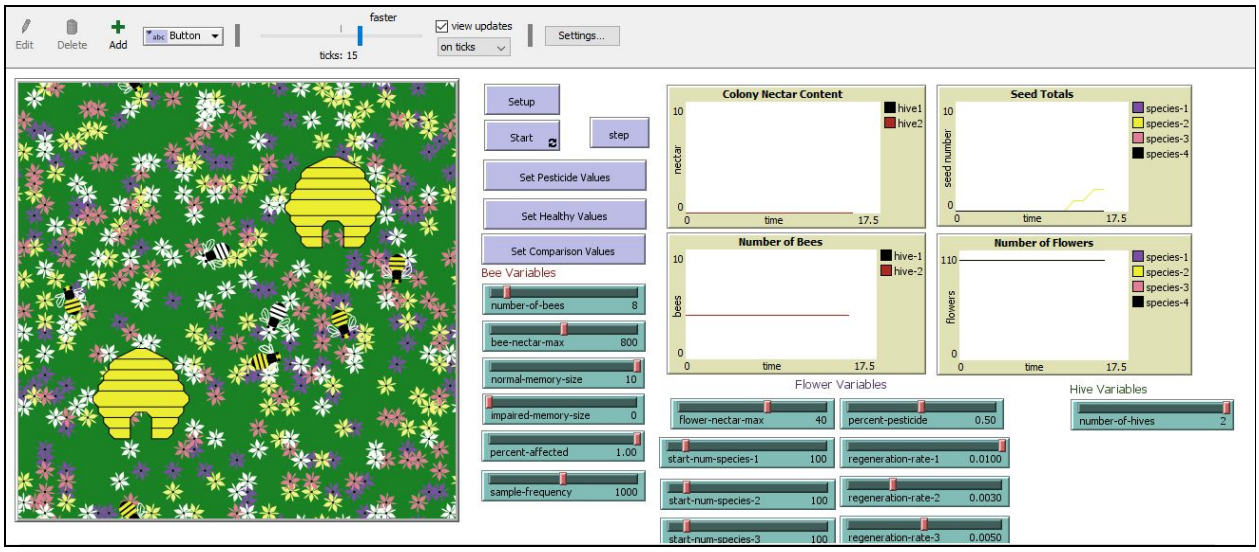


Fig. 6: NetLogo Bumblebee population model that can show effect of decreased bumblebee memory.

As they return to the hive, the resources are deposited and factor into hive success, and as each flower species is pollinated, the seed count increases for that species in the next generation if pollination is successful. Memory in this model could be altered from 10, corresponding to strong memory, to 0, corresponding to no memory and resulting in random flower visits (Fig. 6).

In order to engagingly demonstrate the model, we ran the model to show how bumblebees interacted with the flowers in the environment. Pictures of a population of bumblebees after four seasons not affected by pesticides (perfect memory) were juxtaposed with pictures of a population of bumblebees with completely impacted memory (random visitation) (Fig. 7 Next Page). This demonstration clearly showed how successful pollination of flowers was necessary for bumblebee and plant survival, and that a factor associated with decline such as pesticide usage does not need to be lethal outright to negatively impact bumblebee populations.

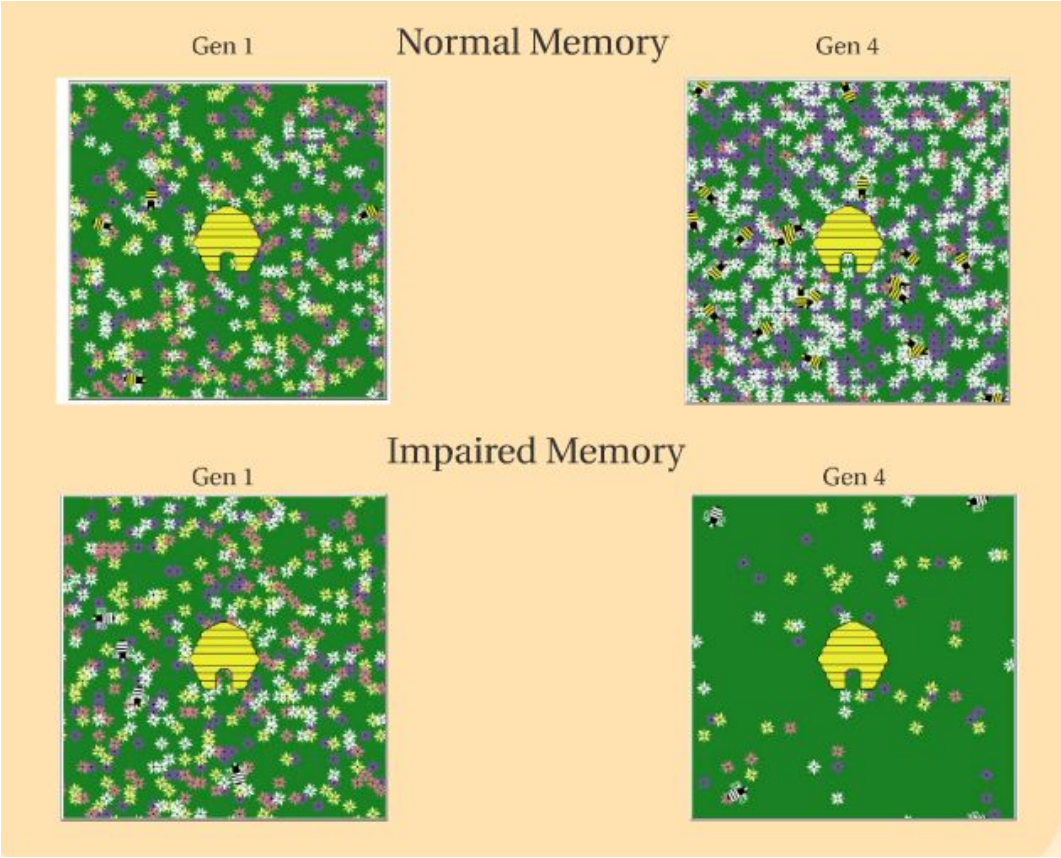


Fig. 7: Slide in Webinar presentation showing the NetLogo Bumblebee population model running over four seasons. The top two pictures show the first and fourth generations of bumblebees with normal memory, and the bottom two pictures show the first and fourth generations of bumblebees with impaired memory.

The final portion of the webinar showed users the upcoming tools in development that would be available in Spring 2018 and later. These tools included the iOS app for Apple users to participate in the project, the videos showing more scenarios demonstrated in the NetLogo model, and the website. Participants were then encouraged to like the Facebook page for updates on the tools, and to fill out the survey on the webinar experience overall (see "IV. Public Awareness > A. Social Media" for more details on the Facebook page).

Webinar Advertising

In order to ensure greater attendance for the webinar and to market the recent developments made in the project, the webinar had three methods of advertisement: a poster, a formal email, and the Facebook page. For attendees of the webinar who did not have access to a Facebook account, an email was drafted briefly explaining the purpose of the webinar and how someone could attend it through the Zoom meeting ID. This method of advertisement was also used by the Western Massachusetts Master Gardener Association to create an announcement about the event. For local attendees such as other students on WPI campus, advertising was done using a poster that would direct them to the Facebook page for the additional details.

The Facebook page was the main source for information about the event, as an event page could be set up for the Bee the Change Webinar. The event page contained all the information for logging into the event via Zoom, and it helped us roughly keep track of attendees for the event. Additionally, since more people have access to Facebook, the event page was boosted for one week in order to reach more possible attendees in Massachusetts. Boosting the page through Facebook allowed the event summary and a link to the event to be posted in the Newsfeed of targeted Facebook users as an advertisement. The targeted audience for this boost was Facebook users in Massachusetts with interests in ecology, conservation, and technology. Overall, the boost reached 894 news feeds, resulting in 94 engagements (either RSVPs or page views). This was a helpful form of advertisement because ⅓ of the survey respondents heard about the event via the Facebook event (Fig. 8 Next Page).

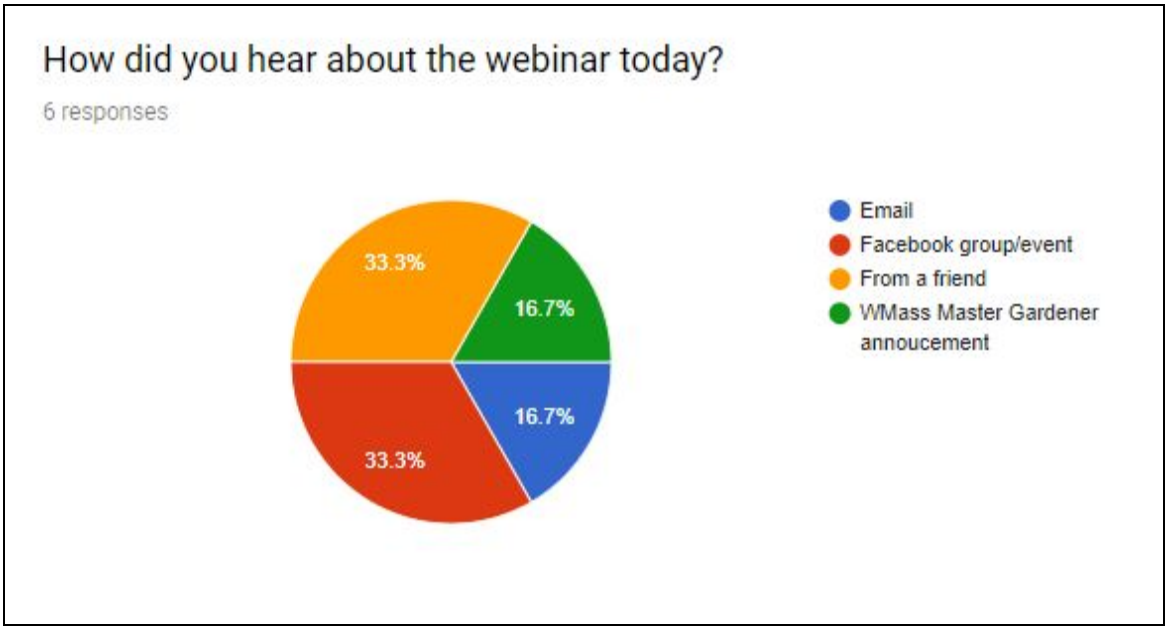


Fig. 8: Figure of where webinar attendees initially heard about the webinar.

Survey responses

Of the 12 participants in the webinar, we received 6 responses to the survey created through Google Forms. The main purpose of this survey was to judge the effectiveness of the webinar as a format for conveying information about the Beecology Project, and to see whether or not it should be repeated. During initial run-throughs of the presentation, the main problem became quality of audio and video for participants. We tried to fix this problem by using a wired internet connection and by not showing a webcam of the presenters after initial introductions. . While this did improve video and audio quality greatly, there were still concerns in the survey results pertaining to "spotty audio". Additional platforms besides Zoom could be considered for future webinars in the Beecology Project, or other methods to decrease bandwidth usage could be utilized.

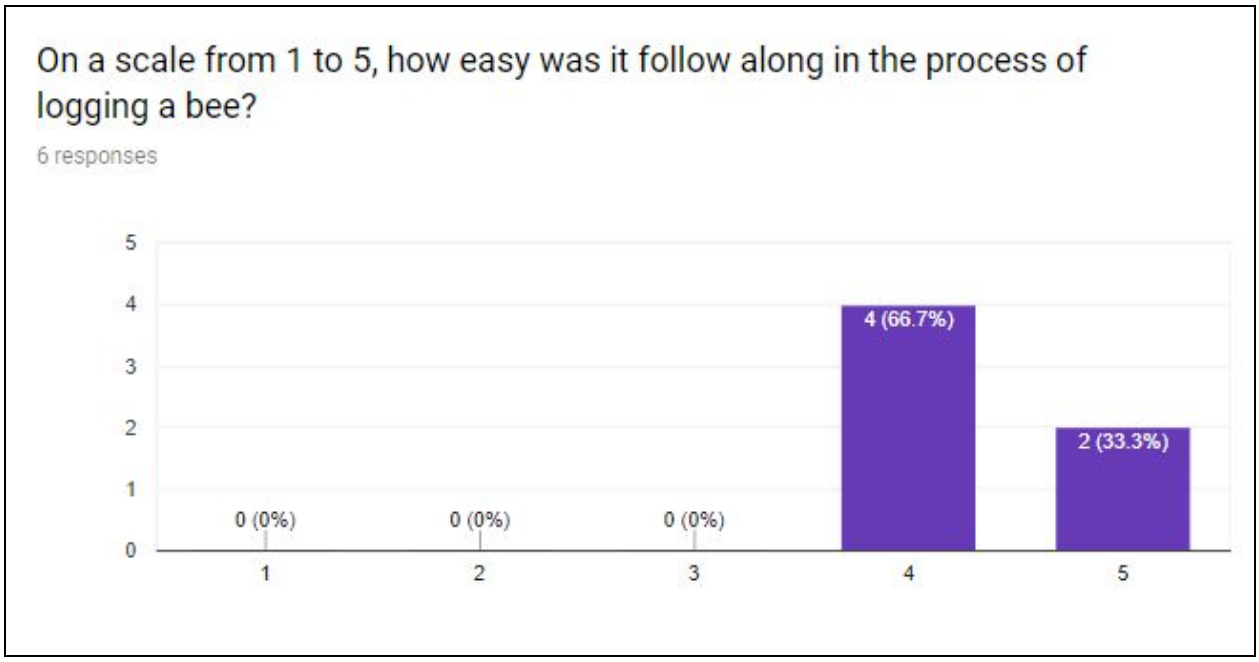


Fig. 9: Results for survey question on effectiveness in demonstration of Android app, where 1- Difficult, and 5- Easy (to follow along).

Overall, survey results were positive when talking about the effectiveness in presentation for the webinar (Fig. 9), since people were able to follow along in the process of logging a bumblebee to the WPI database.

Additionally, when asked about which segment of the project participants would be most excited to contribute to, ⅔ chose adding data to the database, ⅙ chose analyzing database information through visualization tools, and ⅙ chose both (Fig. 10 Next Page). This may indicates a slight distinction in interest for involvement in the project based on available resources, even though there was a small sample size.

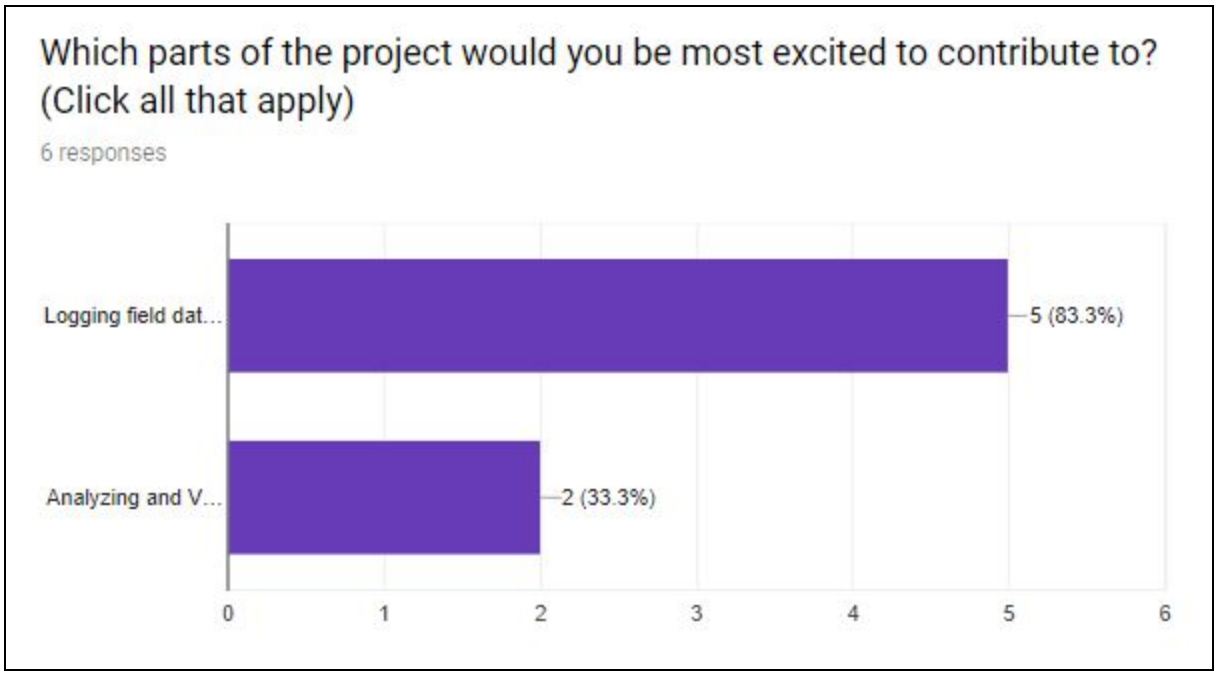


Fig. 10: Survey questions choosing all options that apply for how each participant would like to contribute to the Beecology Project. They can contribute by either logging field data on bumblebees or by analyzing and visualizing data that had already been collected.

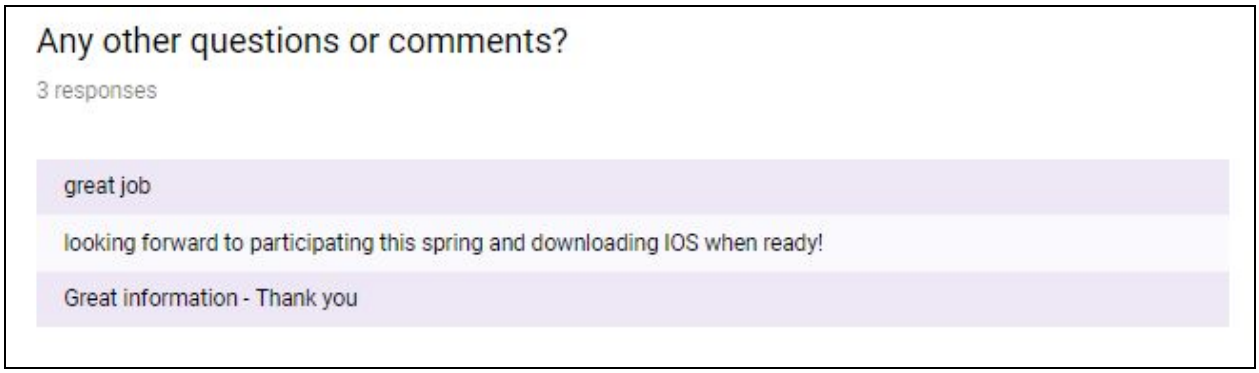


Fig. 11: Comments from webinar participants indicating that the information conveyed was informative and

Overall, the webinar appeared to have positive feedback from participants on the information presented (Fig. 11). The webinar recording was made available for public viewing on the Beecology Project YouTube and Facebook pages after the live webinar so that it can continue to help involve people in the project.

II. Tutorial Videos

Video Development and Editing Process

The tutorial videos were created by combining audio files of a preplanned script with images and other muted '.mp4' files in Windows Live Movie Maker and Shotcut, two free-to-use pieces of video editing software. The audio files were created through a program called Audacity, which allows for recording using either the microphone on a computer or an attached microphone. The audio recordings were created from a read through of the script, and they were edited to cut out long pauses through highlighting and deleting those sections. Once the audio files were edited, they were saved as '.aup' files in case anything needed to be changed. If the audio files needed to be edited, the '.aup' file could be opened, and new recordings could be recorded to replace old ones. If the video required an addition to a current section, portions of silence in the video were copied and pasted into the timeframe for the addition, so that the additional audio could be recorded without interruptions from the previous audio file. The two tracks could then be merged to finalize the addition, and excess silence could be cropped out of the audio.

Once the audio file was complete with edits, it was exported as an ".wav" file and saved onto the computer. All of the ".aup", and ".wav" files can be found in our Google drive folder under "Tutorial Videos>Audio". The Beecology Intro video was made using Windows Live Movie Maker, which can input an audio file, like our ".wav" file, as Music. The Bee ID and Mobile App Tutorial videos were created in Shotcut and have a similar audio entry process. From there, visuals such as non-copyrighted pictures and ".mp4" files were added to match the audio. This could be done by importing it into Windows Live Movie Maker, and dragging it into place in the video. The duration

of each visual and ".mp4" file could be changed by clicking on the picture in the sequence, clicking the Edit tab under Video Tools, and changing the number of seconds in the Duration window.

Pictures that were added could also be modified to include text if it pointed out an aspect of the picture more clearly, and this was done primarily through the software GIMP. A picture was imported into GIMP, and much like in photoshop, new layers could be added to be placed on top of the picture including text and other pictures. Once the picture was done being edited in GIMP, it could be saved as a ".jpeg" file and imported into Windows Live Movie Maker or Shotcut.

Once the video was finished in the editing stages, it was saved as a ".wlmp" file for Windows Live Movie Maker or as a ".mlt" for Shotcut to be edited later. New visuals could be added to the project versions of these files, but in order to publish the video, it was exported as either an ".mp4" or a ".wav" file. Either of these formats could then be posted to Facebook or uploaded to YouTube with descriptions. A Beecologist gmail, beecologyproject@gmail.com, was created for the YouTube account. Once the videos were on Facebook or YouTube, they could be viewed by anyone searching on YouTube or by anyone viewing the Facebook page. Viewers could also comment suggestions underneath those videos for feedback and to help improve them for future developments.

The tutorial videos were designed to guide newcomers to the Beecology project on the use of the mobile app, identification of bumblebees, and the project itself. Each of these purposes is represented by a separate video. Media for these videos was acquired through the Flickr Commons, produced through the use of graphical image editing tools, or live recorded. Each video went through multiple revisions, with the changes focused on improving timing and transitions to keep the viewer engaged. To see the scripts for all of the videos refer to Appendix E.1-E.4.

Beecology Project Introduction Video

The first video introduced people to the Beecology project goals and bumblebee decline in an engaging manner. It will be placed on the front page of the Beecology Project website as a quick introduction to the project, the problems facing bumblebee populations in Massachusetts, and how interested people can get involved in the project. This video also directed viewers to watch the other two tutorial videos that go into further detail on how to use the Beecology Logging Application. For website visitors who had not attended webinar sessions or mobile app demonstrations from Dr. Gegear, this video would be their first introduction to the goals of the Beecology Project and the problem of native pollinator decline in Massachusetts and the rest of the world. Therefore, the video needed to grab the attention of viewers in a short period of time while keeping them engaged and interested in the information we wanted to convey.

With this context in mind, the beginning of the video started with the information that only half of the historically 11 bumblebee species in Massachusetts were now regularly found in the state. Once the viewer was engaged by this fact, the video addressed how this decline could personally affect human populations and the ecosystems and wildlife around the viewer, making them feel more invested in this problem and interested in hearing any solutions. This is the point in the video where the viewer is presented with information about the Beecology Project and how they can directly have an impact on maintaining bumblebee populations in their geographic areas by logging bumblebees to the WPI database using the android and web apps. The video, which was integrated into the website, then continues to present tools available in the website and how they can help the viewer continue to be involved with the data they collected in a larger context. The video presented the viewer with ways the information they collected could be visualized and what questions could

possibly be answered by the visualization tools and an increase in data such as, "What species of flowers do certain bumblebee species prefer?". The video also explained how Beecology Model videos could help educate other people on the effects of seemingly non-lethal declining factors such as the effect of certain pesticides on bumblebee memory over several generations. The Bee ID video also mentions rewards for completeness of records through a higher Beecologist Score. The layout for introducing the elements of the website evolved to this format in order to remain engaging by introducing the problem, while maintaining concise explanations.

Bumblebee Identification Video

The second "Bee ID" video was designed to be watched before the third "Mobile App Tutorial Video", since the information contained in the Bee ID video would be helpful in setting up the use of the mobile app. In order to take a good video of a bumblebee, testing showed that the camera should remain physically within 12 inches of the bumblebee, and the camera's zoom function should not be utilized until modification of the video for a screenshot. While filming, the video should capture an angle of the bumblebee from the top and side views, so that a suitable screenshot can be selected. The Bee ID video elaborated on what data was most important for users to submit in their bee logs with the app, the bumblebee species, characteristics of the flower it visited, and behavior of the bumblebee on the flower. Bumblebees would be identified via coloration on the three bumblebee body segments, the head, thorax, and abdomen, so the angles taken during the video were important for accurate logs. Flower data could be collected along with the bumblebee video, but if characteristics were not clear for the flower, the video recommended that a separate picture of the flower be taken for completeness of the dataset. The video emphasized that behavior of the bumblebee on the flower would determine whether or not it was collecting

pollen or nectar, and that this information is important to collect for determining ecological relationships. If a bumblebee was rapidly moving across the flower while making a distinct buzzing sound, it was collecting pollen. However, if the bumblebee was stationary while darting its tongue in and out of the flower, it was collecting nectar.

Mobile App Tutorial Video

The third video, or "Mobile App Tutorial", focused on covering all of the information that would be covered in a demonstration of the mobile application in person. This information included a walkthrough of taking a screenshot from a bumblebee video, filling out the bumblebee identification guided ID process, and submitting the bumblebee log to the local account and database.

While the Bee ID video summarized the important aspects of a bumblebee screenshot, this walkthrough demonstrated the capabilities of the Android app to obtain these photos. It summarized the three methods of entry for bumblebee screenshots, taking a picture of a bumblebee, taking a video and obtaining a screenshot from the video, and importing a picture to the app from the user's Android photo library. The variety in options for entry were meant to broaden the acceptable methods people could use to submit logs to the database, since some users may be more comfortable using their own cameras or the built in camera on their phones versus the camera hosted in the Beecology App. Since the majority of people will use the video function within the app, the tutorial walks through the app's video editing functions of rewinding, slowing down playback, and zooming in. Since it was recommended that the zoom function not be used until this stage, the quality of the photo taken will be much better at this point even if the user zoomed-in.

The slow playback was also a helpful tool for getting a screenshot as bumblebees move quickly from flower to flower, making it much harder to get the perfect angle at normal playback speeds.

The video then walked the user through selecting a location for the bumblebee, and identifying the color patterns on the abdomen, thorax, and head of a test bumblebee photo. The end product of this identification process was a screen showing the predicted bumblebee species along with its bee model photo for comparison to the user's bee model photo and their original screenshot. If the user did not think the predicted bee matched their own bee, they could repeat the process with different color choices. If it did match, the video walked them through the flower logging process, asking for flower color, flower shape, and bumblebee behavior on the flower. The video ended by describing the process of how the user's logs would be submitted to the database. Since people may not have an internet connection or data connection when they create their log, the Beecology App first saves the submitted logs to a their local account on the phone, independent of any internet access. Once the user returns to an internet connection, clicking the submit and edit logs button within the "My Logs" section would upload their saved logs to the database.

The majority of the core information within the videos remained constant throughout development since it was developed through testing of the application. This information included the distance of the phone away from the bumblebee while filming, the angle at which the bumblebee was to be filmed, and the emphasis on completeness and correctness of bumblebee logs submitted to the database. However, some of the visuals throughout the video did need to change based on newer versions of the app and camera functionality within the app had more limited features at the beginning of the project, so once the zoom and slow-playback tools were added to the in-app camera, the tutorial video needed to change to reflect those added functions.

III. Design of the Beecology Website

Phase 1: Website design

Design considerations

There were three main aspects of the website that were the critical components to include in its design. The first was to provide information about the Beecology project and get people interested, second was to provide hosting for the database and the visualization tools and model, and third was to provide an online web based application that mirrors the functionality of the Android/iOS applications.

The main page of the site should provide any information about the project, conservation efforts, and the beecology project as a whole. Since one of the main goals of the IQP project was outreach, having a central location to host all of the content for the project was critical to this goal. This would provide a platform for hosting the tutorial videos and a FAQ page for the project.

Second, the database and the collection of visualization tools linked to it will be hosted on the site. This incorporates the diversity index and population visualization tool, viewing log submitted to the database, and the model allowing users to utilize the collected data in a visual format and explore effects of pesticide use on bumblebee population and flower pollination rates. These are the key features of the site and are the more interactive parts for data discovery.

Third, the website created by the team will be responsible for hosting the web-based version of the Beecology Application. This is important to allow iOS and other non-android based users to

be able to submit logs to the database without requiring the installation of the Android .apk file or having an Android device.

Apart from these main goals the website had several other important aspects. The first was that it will host our collection of tutorial videos on the proper use of the applications and on the proper technique for recording and identifying bumblebees. The second is downloading the application directly was supported on the site but will later be exported to the appropriate application store, iTunes App Store and Google Play, when the final versions are released.

Initial Site and Webapp Implementation

The web app and accompanying web application was initially created using the Foundations Framework as its template. Foundations was originally chosen because of its responsive front-end for CSS and HTML components. Although technical problems resulted in an eventual shift to the Angular 2 framework, significant effort was expended on the Foundations implementation as described here.

The site's content original content was hosted on an official Worcester Polytechnic Institute CCC server and access could be gained through an external file management system, such as FileZilla, or through more traditional methods such as SSH access through the command line. */var/www/html* is the base file system and contains the layout of the website. The Android Package Kit (APK) file for the download link was located under .../*html/AndroidApp/* folder.

The implementation of the web application was initially designed as a collection of HTML form elements, ranging from radio buttons for multiple choice, Javascript APIs for the map, and textbox entry for collecting strings of information. The application was originally implemented as

three separate forms that pass data to one another through a series of scripts and submitted to the database through an Asynchronous JavaScript And XML (AJAX) function. Each form was responsible for a different aspect of the application. The first form, "beeform", was used for the collection of initial information through a series of radio buttons that interact through javascript functions. The second form was the "summaryForm" and information about the bee was pulled from “beeform” and used to populate “summaryForm”. From here there was a javascript function that validates the selected elements and determines if the selection of bumblebee parts by the user was a possible valid combination. The final form was "confirmForm" and of the three was the only form that accessed the POST method for database submission and the AJAX function. This meant that to submit to the database the user must first be able to access this form after a valid selection of bumblebee parts. This final form pulled all the elements from beeform and presented them in a clear list for the user to review once more before submission to the database, or alternatively to go back to “beeform” and edit any of the entry fields before returning to “confirmform” and submitting to the database. The submission was originally handled through an AJAX function, but because of issues with the encoding of the image file was removed to prevent erroneous submissions to the database.

Several technical issues were encountered during implementation of the BeeID webapp

1. The display of sectional images for the bumblebee parts
2. The lack of a validation function for the selection of bumblebee parts
3. The submission of a photo and/or log to the database.

The issue of displaying the images for bumblebee parts was on the front end of the site and one of the reasons that the site framework shifted from Foundations to Angular 2. The first

problem was in the identification process, where a selection was made for the initial base bumblebee coloring (i.e. black, yellow, or half). As an example, if the user selected black as the initial bee coloring, the options for yellow and half are still displayed instead of being unselectable/hidden, Because of the Foundations framework this made making a valid combination of selections increasingly difficult since all of the options and images are displayed and there was no way to hide an element that is not being used.

A second issue arises not from hiding the extra elements but from attempting to reload them if a new base color selection is made. For example, if one selects "half" there are four options for the thorax while "yellow" has six; if the user selects "half" first when they then change their selection to "yellow" the remaining two elements come back jumbled and not in the correct order or association with the given radio buttons.

The validation of bumblebee parts also posed an issue for Foundations version of the web application. Without a reliable method to manipulate the bumblebee part options (as described above), we couldn't safely rely on the current version of the application to pass along the right elements to the other forms or even the database. Therefore a function to check if the users selected values are a valid combination of parts that form a species of bumblebee is required, however because of the issues mentioned the validation of the sections was inconsequential because even if a correct selection was made it was possible for the Foundations framework to jumble the values and pass an invalid answer as valid to the database.

Finally, the submission of the photo to the database was an issue on the server side. When encoding the photo upon submission to the database the server only receives the string representation of the photo. From here the database has no way to either decode the photo, if

possible, and cannot receive the photo in the initial format given by the HTML upload function located in the first field of the "beeform".

Because of these issues the current version of the site has made the change from the Foundations framework to using the Angular 2 framework. Angular 2 was released during while the project was ongoing and was not originally considered. The change was made because the new team knew that Angular 2 would resolve the issues being encountered in Foundations. This new version being created is being developed by a separate team and does not use the code created for the Foundations version. More on that in the final section about the future development of the website.

Phase 2: Website Mockups

Due to the difficulty in designing the web app, the focus of the project was shifted to creating content to recruit new beecologists and to provide active beecologists with useful information and online resources. . This would include the project background, the previously mentioned tutorial videos, along with both versions of the mobile app(IOS Web and Android). The focus was to create mockups for the design and content of the various pages; these would be passed along to a separate team of developers to implement the site. In addition, the functionality of the web version of the mobile app and the data visualization would be considered out of scope for our team; the technical implementation of these tools would be handled by a separate group.

Creation of the mockups themselves was done using the cloud service draw.io. This enabled the use of pixel metrics and hexadecimal color values for ease of conversion to HTML and CSS. Other design tools were available, with Adobe XD and Microsoft Visio as the leading competitors. However, neither of these are multiplatform with regard to linux-based operating systems, and neither were considered affordable; both of these were hard requirements for our team. Draw.io

required only the use of a browser that supports javascript, which all team members could accommodate.

In some cases, it was necessary to create diagrams of ecological concepts and project data flow. In these instances, media was obtained from Freepik.com, citing their works through an inline HTML block. This license enables the use of the work as long as the block is included somewhere in the page. These citations would be passed on to the development team along with the mockups. Finally, media was then arranged in draw.io to form a singular diagram.

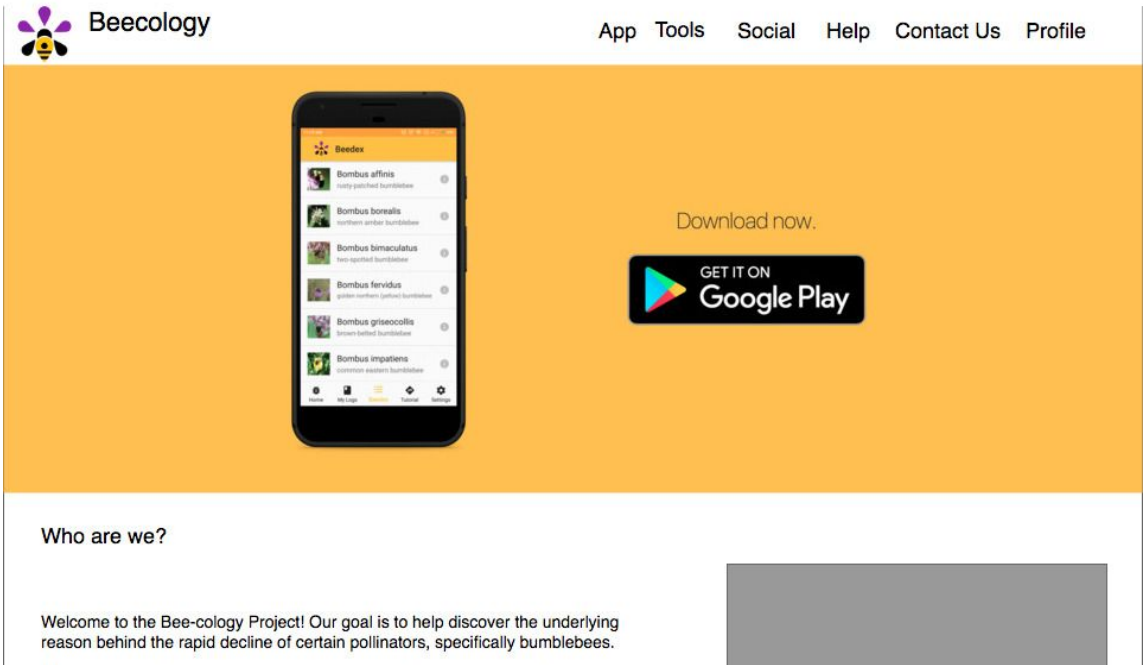


Fig. 12: The front page of the Beecology Site

The front page of the site would provide users with basic information about the project and its goals, along with a scrolling header of current news or updates (Fig. 12, and Appendix E). Below this, branch points would direct uncertain users to whichever portion of the site was relevant to their interests. Three branch points were created, one for contributing data to the project via the mobile app, one for visualizing and analyzing this data, and one for observing simulations of environmental

effects on honeybees. These branches would link to the mobile app tab, the database visualization tab, and the simulation tab, respectively.

Site navigation was implemented primarily through the use of tabs (See Appendix C for details). The design of these tabs was edited several times throughout iterations of the website mockups, since we initially had each of the tabs visible from the homepage without hovering a mouse over them. The final design was chosen to reduce the initial number of tabs on the page, shrinking the horizontal size and allowing for better display on smaller screens. By grouping tabs with similar functions into categories this way, the website would be easier to navigate while remaining friendly to PC and mobile interfaces. In addition, the dropdown tabs would enable us to easily add more tools in the future without significantly changing the layout of the site.

The App tab would link to page where the user could select either the android app download, or use the web app directly. Since the Beecology App would be the primary tool for contributing iOS users, it was put first on the website. Since iOS users would come to the website to log bumblebees, the first tab on the site would be the tool they need to accomplish that task. To keep things simple, the layout for the web App and the Android App would be identical. This way, both Android and iOS beecologists would use the same tutorials, and users could help each other in the field even if they use different types of phones.

The Tools tab would display a drop down menu of three tabs, bumblebee background, data visualization, and the bumblebee simulation model. Background on bumblebees and the role that they play as native pollinators is essential in the education of citizen scientists; therefore, the information provided on the background tab would give a synopsis of the importance of bumblebees, the problem of bumblebee decline, and the Beecology Project's solution to that problem. In the Background tab, we first give the definition of a pollinator for users who are

unfamiliar with the term. Next we used a diagram to describe the difference between managed pollinator decline with honeybee populations, and native pollinator decline with bumblebee populations. Since managed pollinators abundance can be controlled by humans, and native pollinators species diversity and abundance can only be influenced by humans, any misconceptions about this relationship needed to be cleared. The importance of bumblebees, the decline of bumblebee populations, and the Beecology Project are also defined and represented by charts on this page. We included this information because it is the primary source of information on pollinator decline for Beecologists who have not gone to any events, so the information needs to include what would be presented. The data visualization tab would host the visualization tools currently being developed to see various aspects of data collected in our Beecology database. Tools that display bumblebee data on a map can be filtered by species and diversity currently, but more tools are in development to model a user's specific entries, floral information, and possibly outside factors that could influence bumblebee populations. By visualizing the data through these graphs, charts, and maps, we will try to find patterns in bumblebee decline for specific species, and we will try to identify specific bumblebee and floral species needs for success.

When mousing over the Help tab, user have the ability to click tabs to show the Tutorial videos page or the frequently asked questions page. Given the potential complexity of the tools created and the range of experience in our target demographic, it was necessary to provide helpful information for the public. Three videos were created with one explaining the process of using the mobile app for data collection, one clarifying the process of identifying bumblebee species and behavior and one as an introduction to the Beecology Project and its goals. Each video involved creating a script, finding or producing relevant background footage, and using video editing software to cut and join the recorded script and imagery. Each of these videos would be hosted on the

website, further cementing the site as the central hub for information on the app and bumblebee decline. The frequently asked questions tab was created based on initial feedback from using the app, and it provides answers to questions about the website, bumblebee decline, and the Beecology application. It also includes a few links to outside sources that provide detail about bumblebees.

The Contact Us tab provides the contact information for the Beecology administration team, so that people can email specific questions if needed. It also includes a more detailed description of the Beecology Development team as an 'About Us' section; photographs of the team members and advisors are included, and each group is divided into how they contributed to the project, whether through app development, website development, or database development.

The final tab we wanted to include was a way for users to login to their unique accounts when logging bumblebees. This page was unique since it not only provided the user with a means to log into their own profile, but it allowed users to customize their profile and information. As a means of enticing more users to remain committed to the Beecology project from a competitive demographic, a Beecologist Score would be promoted on this page. The Beecologist Score is a gamification idea that would encourage users to log more bumblebees by adding to the user's personal score for each time they log a bumblebee. The logs would be given points for completeness, accuracy of fields, and rarity of species of bumblebee. Additional titles would also be awarded for specific point ranges, and people within certain point ranges may be featured on the main page of the website or on the Facebook page. The reasoning behind making a Beecologist Score versus a Beecologist Leaderboard for specific categories was made partly because an increase in direct competition with other citizen scientists may lead to inaccurate or false logs of more rare bumblebee species. We wanted an element of competition to exist but not at the expense of an accurate data set.

With the design of these tabs as website mockups, we laid the groundwork for a friendly user interface that is intuitive to navigate and representative of the Beecology Project's goal of education.

IV. Public Awareness

A. Social Media

While the features of the webpage are currently being developed, there is a need for a social media page to begin reaching out to communities of interested people in Massachusetts. The majority of data supplied to the database will be collected by citizen scientists, so the Beecology project social media presence will be an important hub for communication between administrators of the Beecology project and citizen scientists. The Beecology website will be a platform for hosting the information we wish to convey, but the Beecology Project social media presence will generate interest in the project, leading to more visits to the website. The elements of the Beecology Social Media presence included the YouTube channel and the Facebook page, each of which providing different services to the Beecology Project.

The Beecology YouTube and Facebook channels are both referenced at in-person events and webinars as the methods for communicating with and learning about the Beecology Project.. The YouTube channel was created as a platform for hosting any videos created by the Beecology Project. It is referenced by other forms of social media and allows for viewers to comment feedback about the clarity of the video and how it can be improved. It also gives those users who do not have Facebook accounts access to the tutorial videos. The YouTube page was initially made by creating a Beecology Google account, and additional information about each of the videos was added in their descriptions.

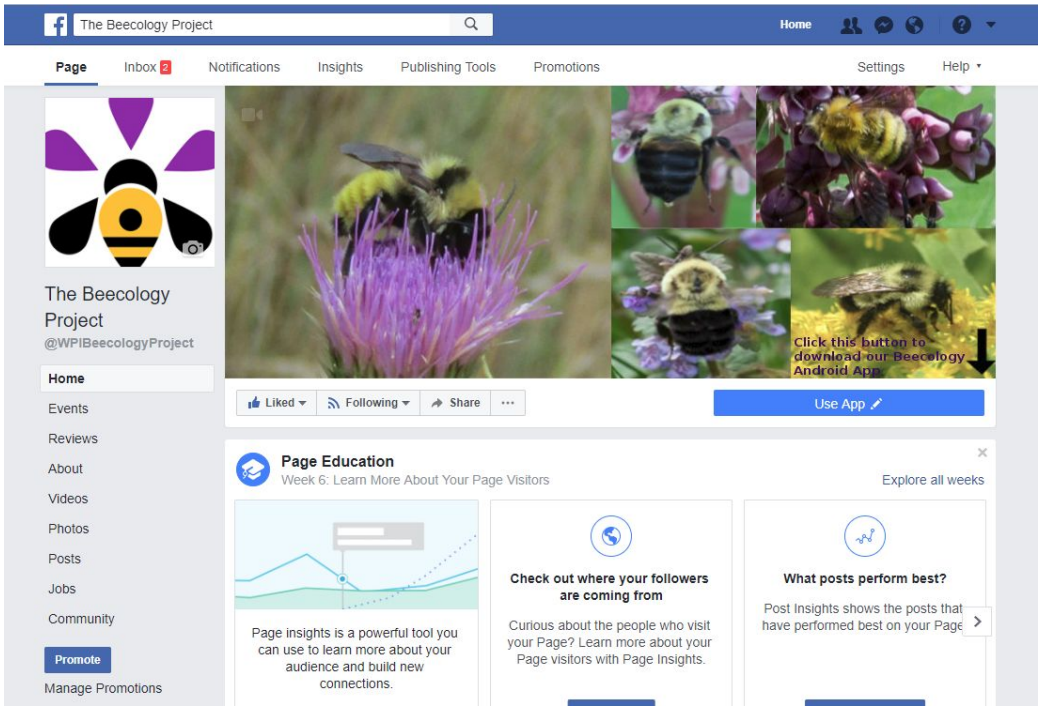


Fig. 13: The Beecology Facebook page

The Beecology Facebook page (Figure 13, above) was created for hosting community conversation, and contains several helpful links for users. The page would also share the role of advertising for events, additional webinars, and other beecologist community gatherings with email listings. However, while email listings would reach out to known conservations communities in the contact lists of Beecology administrators, the Facebook page will be integral in reaching out to new communities that want to get involved. The Use App button below the cover photo allows any user to directly download the Beecology Android app. Once the Beecology website is functional, the Android app download will be available there, but this button allows users to download the app for now. The Events tab will give users access to any events created by the Beecology administrators, such as in-person events and additional webinars; users can also RSVP to those events directly through the event pages. The Reviews tab allows users to give feedback on the user-interface of the Facebook page and the Beecology Project overall, creating a powerful tool for promoting positive

reviews and addressing user problems. The About tab contains a description of the Beecology Project, along with an email contact for the project so users can contact Dr. Gegear directly through the "beecologyproject@gmail.com" email. The Videos tab is another location for the tutorial and intro videos hosted directly on Facebook, and the Photos tab contains citizen scientist highlighted photos and species photos for all bumblebee species historically found in Massachusetts. The Posts tab allows users to see the previous posts from the Beecology page, and as long as they 'like' the page they will be notified of any posts made by Beecology administrators about tool development in posts. Lastly, the Community tab allows users to see other people in the Facebook community who have 'liked' the Beecology Facebook Page.

B. Brochure

The purpose of the brochure is to provide a cheap and effective means of communication that can be distributed at events or left at various locations. The brochure communicates to the reader the issues of pollinator decline, how they can help become part of the solution to the problems facing pollinators, and finally about how diversity of species is as important as protecting an individual species of bumblebee. In the methodology section it informs the readers of the issues and questions that project is trying to resolve as well as several other aspects that related to the outreach goal.

The main focus of the brochure is to be a means to inform the reader about the causes and issues affecting pollinator decline. This is addressed with several sections on the types of pesticides that kill bumblebees, why plant diversity matters, and the caption on the front page of "Help us protect our local pollinators" as a call to action to engage the reader and let them know that the brochure is about being a participant as well.

Secondly, the brochure informs the reader of how they can become part of the solutions via the Beecology application. The middle pane shows the user "You" as a part of the project schema alongside environmentalists and other researchers. It also conveys to the reader the causes of pollinator decline, impacts on flower diversity, the effect of pesticides on bumblebees, and the fact that they don't create honey and instead are critical for pollination of consumer crops and wildflowers. All of which have questions that we need their contributions to answer.

Finally, the brochure is to a way to communicate the idea of pollinator diversity to the reader. Several sections highlight different types of bumblebee species and others focus on what is not a bumblebee, and a section on why the diversity of the flowers also matters to the bumblebee diversity furthers the outreach goals attained by the brochure. On the back, there is a small quiz (Seen in Figure A.1) designed for the reader to take home and test the current diversity status of their garden. This is an effective outreach tool because many of the beecology lectures take place at local gardens, and hopefully, many of the gardeners attending will be interested enough to take the quiz and see how well they did. It consists of asking them how many of five flower types they have, finding any of eleven species of bumblebee, and if they use pesticides. Once completed they find their score out of a hundred. Then based on how they did, their score tells them more about the status of their individual gardens diversity.

The brochure was created using Canva, a free platform for creating distributable content. A pdf copy is located on the google drive in "IQP-Sam-2017,18/Brochure Drafts/Planning". This copy however cannot be edited since it requires Canva. To edit the content of the brochure sign into https://www.canva.com/ with the beecology@gmail.com email account and the brochure is saved to the account there and can be copied or changed easily at any time.

Conclusions and Future Projects

I. Summary of IQP Goals

Our Interdisciplinary Qualifying Project (IQP) team had four primary goals we aimed to accomplish. Each goal had several aspects to it that we then developed into accomplishable tasks with our advisors and completed over the course of E term 2017 to C term 2018.

Goal 1. Create and host a live Webinar on the Beecology Project. To accomplish this task we drafted and finished a script for the webinar, created a Prezi as a visual aid for the viewers, set up the Zoom platform for screen sharing, and created a small paper bee model for a live demonstration of the application. We then promoted the webinar through email and a facebook post that we promoted. The actual event was held on Saturday February 24th. After the event we received feedback from the viewers via a survey that we also created; the survey focused on how much they felt they benefited from the program as well as open response to how well the webinar went from their perspective.

Goal 2. Create Tutorial Videos to help Beecologists learn how to use the app and properly identify bumblebee species in MA. To accomplish the second goal we drafted and finalized a series of scripts and images for each video. We then recorded each video, and each one is now hosted on the Beecology Project YouTube channel as well as the Beecology Project public facebook page.

Goal 3. Design of the Beecology Website. When the first goal of creating the site using the Foundations framework was not possible to accomplish, our goal became to create mockups for the next team that is using Angular 2. We created the mockups using Draw.io, a free diagramming

software package. These designs were then passed on to the web design team to use as templates for the site they are developing.

Goal 4. Design a Beecology Informational Brochure. To accomplish the last goal we designed a brochure using Canva, an online resource for promotional content. Through several drafts a final brochure was finished and can be printed and used as a handout for future events or provided a relevant location, such as a public garden.

II. Beecology Future Projects

The 2017-2018 Beecology IQP project was able to lay a foundation for quicker and easier integration of new users into the Beecology project. Through tutorial videos and written instructions, we were able to guide new users through the process of logging a bumblebee using the Beecology Android app while helping them understand the importance of high bumblebee species diversity. The webinar, brochure, and our social media presence gave new users the option to converse with fellow citizen scientists while publicizing the project and giving us feedback on how to improve our tools. Since this project was user focused, we designed our help tools to address common problems people may have when initially starting their involvement with the project. Though implementing the website was not a goal of the project , the mockups were carefully designed by our team to be intuitive and easy to navigate, giving users the best access to information surrounding the project. Each of these products and events aimed to introduce new users to the problem of bumblebee and native pollinator decline in the easiest way possible.

There are several project goals that we would recommend for future projects to expand upon the products we have given and those that have yet to be released:

1. Modification of help tools based on new app versions and user feedback

The duration of the current IQP project goes until the start of Spring 2018, and the web based App for iOS users is on track to be finished before the Summer 2018 season. Additionally, the website will be developed based on current mockup specifications in the near future. New database visualization tools will be hosted on this website to model many kinds of bumblebee data. With all of these new tools, it may be useful to create a tutorial video about how to use the database visualization tools and what they can show. Once the website is implemented, it would be useful to get feedback on its user interface so it can be modified accordingly. We were not able to showcase the tutorial videos to a large enough audience to receive reviews and feedback, so the current videos and Facebook page could be shown to a larger audience and modified based on feedback.

2. Widespread advertising or targeted advertising

Advertising for the Beecology Project was largely successful in the use of email, Facebook, and the webinar, but more kinds of advertising could be utilized. Depending on the number of users the Summer of 2018 brings to the Beecology Project, targeted advertising could be utilized. The Facebook promotion page and other conservation platforms could be used to promote events. For areas in Massachusetts with less bumblebee data collected by citizen scientists, media sources in that area could be contacted to publicize the Beecology project. More widespread advertising could be used for promoting the Beecology Project website and applications by talking to newspapers and radio stations. If stations are given a completed, local story about bumblebee/native pollinator decline in Massachusetts, they may be willing to help us with advertising. It may also be useful to create a Facebook advertisement for the Beecology Page or to boost any new events for the Beecology Project, since larger amounts of money invested will result in greater numbers of

Facebook viewers seeing the Beecology Project. This boost or advertisement can be targeted towards a specific group in Massachusetts based on Facebook interests, or it could be more generalized.

3. Live demonstrations of tools during active bumblebee seasons

One of the key disadvantages we found during our project was that we completed our project over the fall and early spring season, whereas bumblebees are active from late spring to the middle/end of fall. Not only that, but most bumblebee foraging peaks are during the warm summer months in June and July. During Summer 2018 or Summer 2019, it would be useful to test how effective the android and web apps are at recording large amounts data in live demonstrations. Going to conservation sites or arranging an activity with a university or school would be helpful to get access to a large test group, then changes could be made based on feedback from those groups. Parts of the project such as tutorial videos and website features could be tested by these larger groups, and if there is some kind of financial incentive for participation the group size could be even larger.

4. Ideas for Facebook Page Activities

Since the Facebook Page is set up to be a large part of the outreach to the citizen science community, there should be posts on the page promoting how we want it to be used. Not only can new tools be announced on the page, but weekly activities for conservation, and rewards or recognition could be utilized to boost participation. For example, the Facebook page could recognize the top 5 citizen scientists each week with the highest Beecologist Score, which is a score based on the correctness and rarity of each user's bumblebee records. Facebook events could also be utilized to rally groups of people together to look for bumblebees in areas with fewer bumblebee records in the database. These excursions could be directed by Beecologist administrators, or it

could be independently run by smaller groups. There should also be events for increasing conservation efforts and mindfulness towards bumblebee diversity, such as garden ranking for supporting bumblebee species diversity.

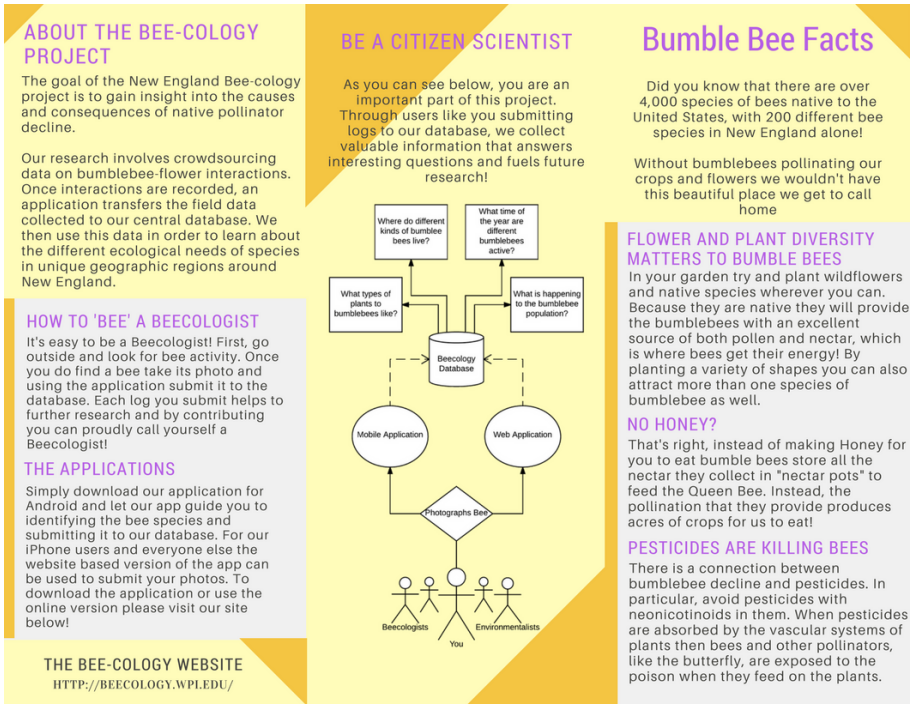
Overall Conclusions

The 2018 Beecology Project IQP helped to further the accessibility of the Android application for the general public while laying the foundation for the website to be implemented with a friendly and modern user interface. The suggestions for future projects will help to promote new tools for the Beecology Project such as the website, while increasing effectiveness of old tools based on feedback from users from our targeted demographics. We would like to thank all of the people who have helped us along the way with finishing the project, and we hope that this project will make a lasting impact on conservation efforts concerning our native pollinators.

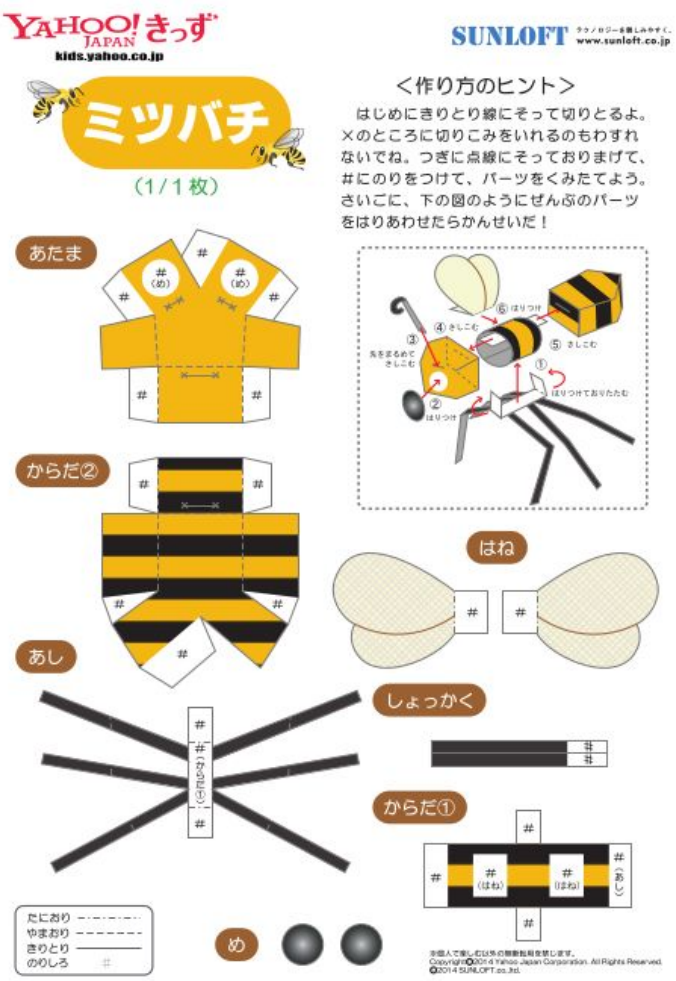
Appendix

Appendix A: Figure A.1: Brochure Front

Figure A.2: Brochure Back



Appendix B: Fig. B. Bumblebee model (Fig. 4) expanded:



Appendix C: Figure C.1: Website Main Page

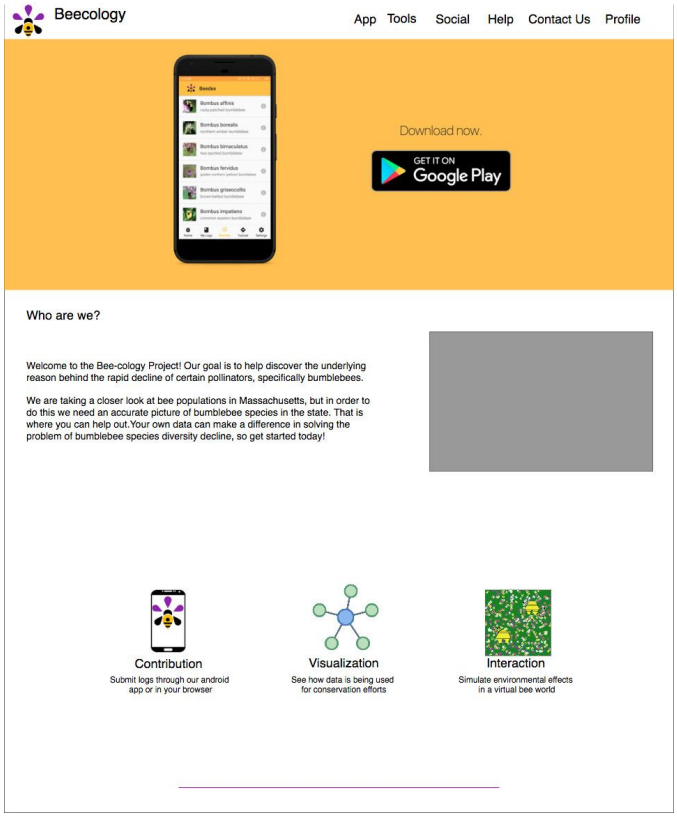


Figure C.2: Beecologist Profile

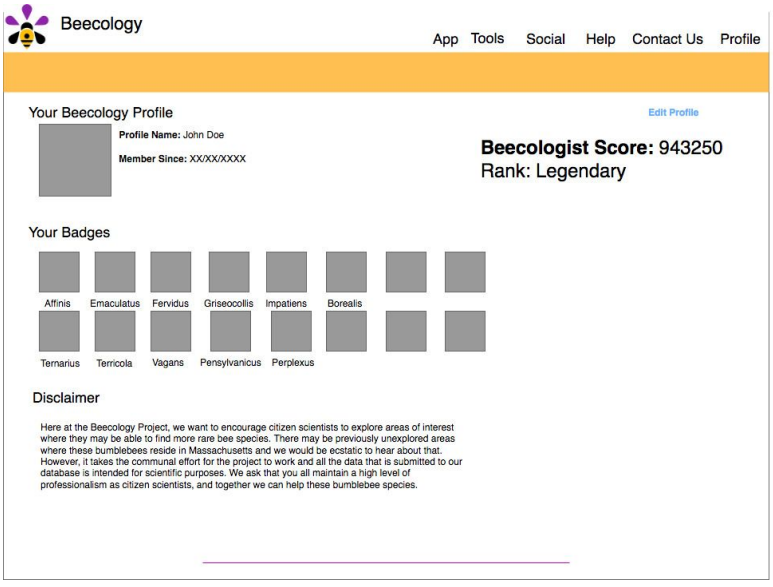


Figure C.3: Website FAQ

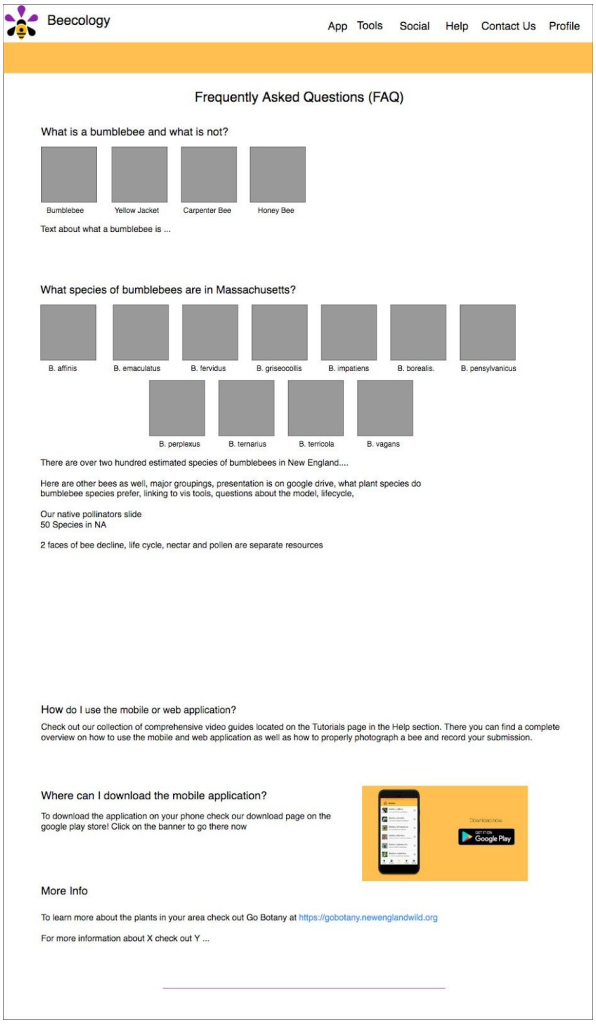


Figure C.4: Website Meet the Team

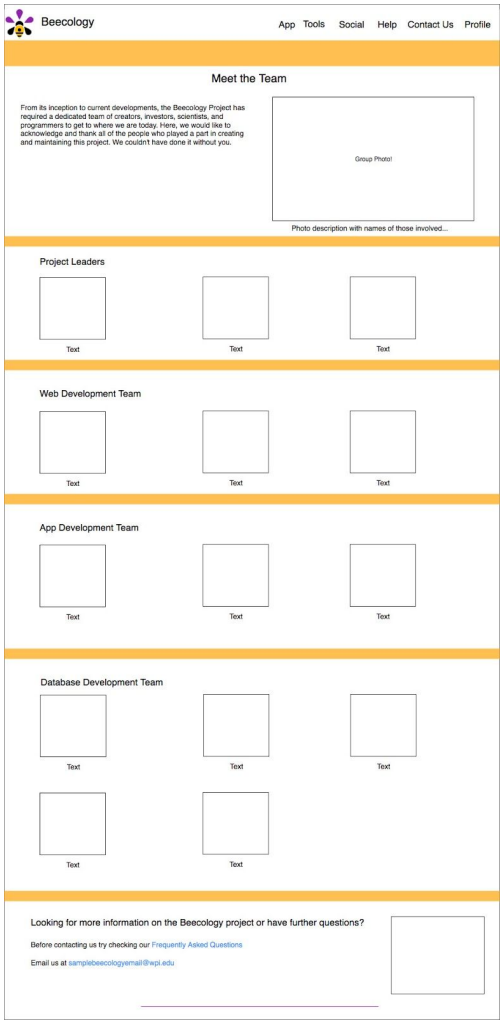


Figure C.5: Website Tutorial Videos

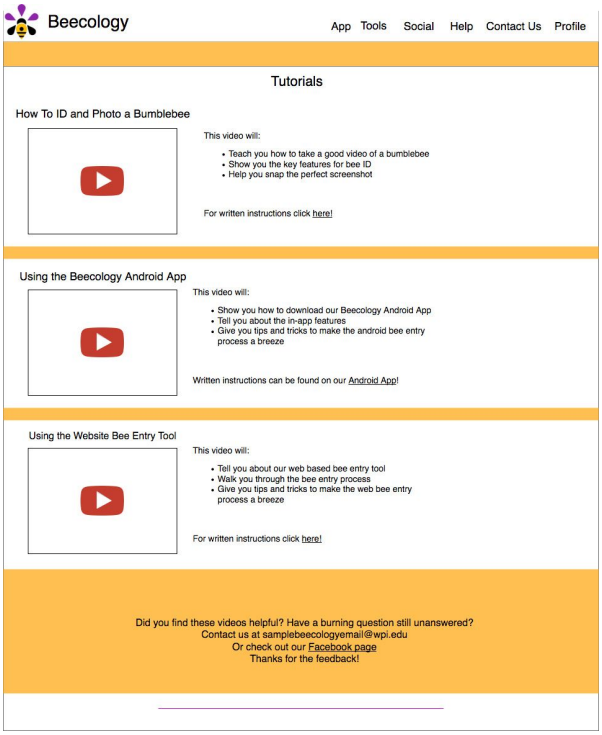
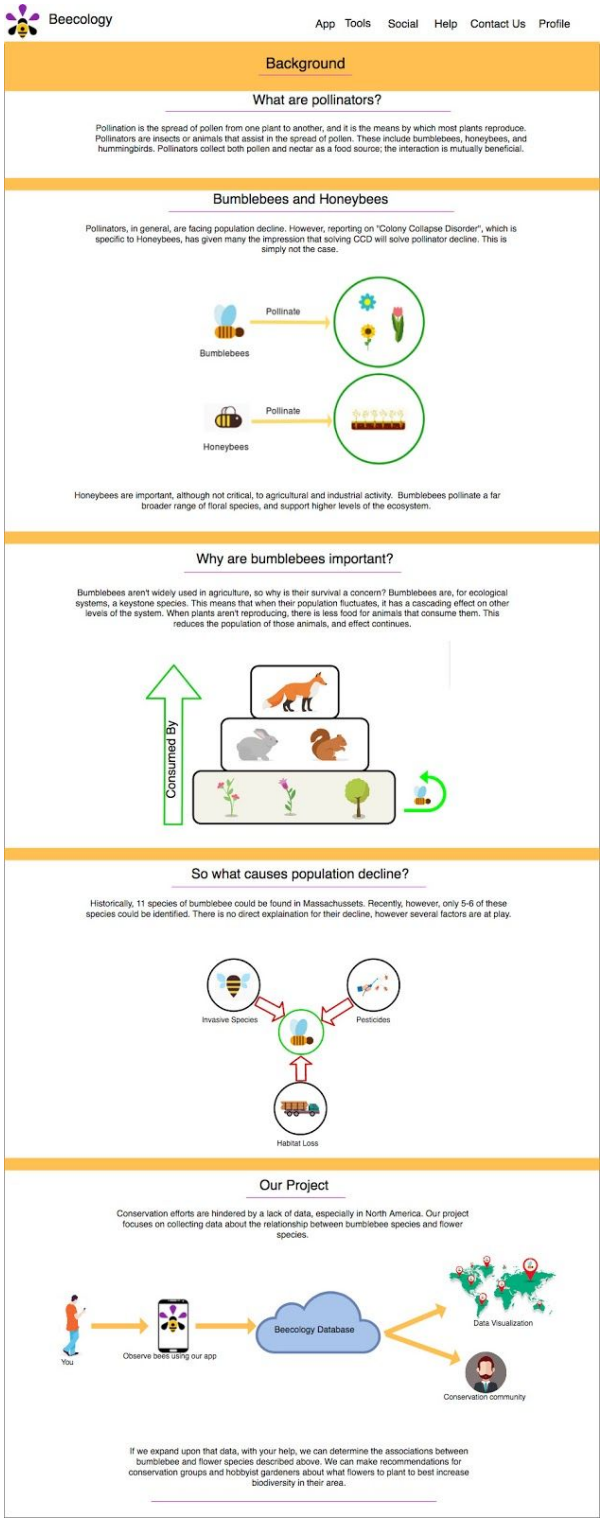


Figure C.6: Website Background Information



Appendix D: File Location References

All Resources for the 2018 Beecology IQP can be found at the following Google Drive Location:

Bee-cology Project > IQP-Eoin-Ken-2017-2018 > Resources

A README text document in that location explains the organization of information.

Appendix E: Transcripts for Tutorial Videos

Appendix E.1: Script for Web App Data Entry Video

0:00 - This is the video describing the bee log entry process for Apple products and PC users. If you are using an Android, please click on our Mobile App Data Entry Tutorial video instead. That being said, let's get started.

0:20 - Here you will learn where to take your bee video on your iPhone or iPad, how to get a screenshot, and how to submit your entry to our database in a few easy steps.

0:30 - On an iPhone or iPad, you will take your video on the your regular camera app. Exit the Beecology website and open your camera app, then take the bee video as specified in the Bee Identification video (6 to 12 inches away from the bee, without zooming, and with top and side views). With your video in hand, the next step is to take a screenshot. An ideal screenshot is best taken from a top or side view of the bumblebee. Zoom in to get as much of the bumblebee in frame as possible. Scrub through the video until an ideal screenshot is in view. Here is an example of a good shot. Even though it can be blurry, as long as colors on all three segments of the bee's body are in view, the picture will work. In this bad shot, not all parts of the bee are visible. Even if the photo quality is "National Geographic worthy", if not all parts of the bee are in view, the species cannot be identified. Once you have your frame, press the power off button and the home button at the same time to take your screenshot.

2:15 - Great! Now that you have your picture, you can fill out your bee log found at the Web Application tab on our website. Here you'll see an option to upload your screenshot, as well as the rest of the submission form. Upload your screenshot by clicking "Choose File" and then selecting your screenshot. Then enter the date the photo was taken as well as the location where you found the bumblebee. You can click the location manually, or search for the location in the search box.

2:30 - The next questions ask about the coloration on the abdomen, thorax, and head for the bee. Using your screenshot, choose which color description of the abdomen best matches your bee represented by mostly black, half yellow/half black, or mostly yellow sample photos. Once you've worked through the form characterizing the colors and patterns of the head, thorax, and abdomen, fill in as much information about the flower name, shape, and color as you can from either the screenshot of the flower, or the separate photo you took earlier.

3:00 - Finally, enter your email on the last section of the form. We will not be sending you any spam, and your information won't be posted; we just use your email as an easy username for your ID to look up previous submissions.

3:30 - Once you are satisfied with your submission, click "Confirm Your Bee". This will bring you to a page with one of our stock photos of the species that best represents the options you chose for your bee. If you think that the bee still matches your photo, click "Review your log". Otherwise, feel free to go back and edit any information by clicking "Go Back"

3:45 - You'll have one more chance to view the information you provided, and if you're satisfied with your entry, click "Submit to Database". Congratulations! You just logged your first bee, and contributed to the Beecology project's larger effort to help conserve bumblebee species in the Northeast. We hope this video has been helpful to get you started, and if you have any further questions, feel free to email us by clicking on our "Contact Us" tab. We thank you greatly for your help and wish you the best of luck in your quest to "Bee"come the buzz of the project.

Appendix E.2: Script for Mobile App Data Entry Tutorial

0:00 - Welcome to the BeeCology Mobile App Tutorial! If you're reading this from the BeeCology web portal, you can find a download link for the mobile app below this video, and a link to our app on the google play store.
0:20 - To launch the app, tap the BeeCology icon from your apps launcher, or on your home screen. **From here, you have several options for logging a new bee:**
- Take a still picture using your device's camera
- Take a video, and use editing tools to capture the best still frame
- Or, import a picture you've already taken
On the bottom bar, you'll find other helpful links:

- **You can view your logs, and submit to our database**
- **Open the beedex to get more information about local species**
- **Read a tutorial about how to take better logs**
- **Or open settings to log into your account**

00:50 - Let's try logging a bee. (Note: don't re-record anything related to permissions) The app will ask for permission to view your location, but this is only to keep track of where you find the bee's you log. Once you've taken you video that is 6 to 12 inches away from the bee, with the bee seen from top or side views, you can use the scrolling bar below your video to slow down the footage and take a still image of a clear frame. Here is an example of a good shot. Even though it can be blurry, as long as colors on all three segments of the bee's body are in view, the picture will work. In this bad shot, not all parts of the bee are visible. Even if the photo quality is "National Geographic worthy", if not all parts of the bee are in view, the species cannot be identified. If you already have an image of your bee, you can upload it from your photos.

First, choose how you would like to observe your bee. If you have a clear view of your bee, you can take a still image directly. If your bee is moving quickly, you might want to take a video. Afterword, you can slow down the footage and take a still image of a clear frame.

If you've take a video, you can slow the footage down afterword. Try to look for a clear frame, and zoom in if your bee is too small. Then, you can take a still image of the best frame.

1:20 - Once you have a clear picture of your bee, you'll be asked to verify the date, and select the rough location you took your photo. Pan around the map to select a location. Previously selected locations will be saved, so you can add multiple bees from the same location easily. Select 'Guided ID' and you will be asked a series of question about your bee's physical attributes. If you cannot clearly see the features described, you may wish to take a different picture at a better angle. First, roughly select the color distribution on your bee's abdomen. Then, you will be asked to scroll through a series of color patterns that may match your bee. Select the closest match. You will be asked to repeat this

process for the thorax and head of your bee. As you do so, the graphic on the left of the screen will update with your selections. This should be used to compare with your chosen image on the right. When you are done, select 'Identify my Bee', and you will be shown the species, and an image of the bee that matches your selections. If this is incorrect, select 'Not my bee' and start over. Otherwise, we can continue to identifying the flower your bee is on.

2:00 - If possible, you should identify the flower your bee was on, and what behaviour it exhibited on the flower. Give the flower a name. These are for record purposes only; you do not need to know the exact species of the flower. **Select the shape of the flower from the dropdown menu.** Then, select the color of the flower. Next, determine if your bee was collecting pollen or nectar while it was on the flower. For determining this, see our other tutorial section on "Identifying bees and behaviour".

2:30 - From here, you can submit your log to your local device, and submit it from the 'Logs' button on the home screen. You will be asked to provide your email address for identification purposes. From this screen you can view your logs, and submit any previously unsubmitted log. That's it! Your logs will be received by our system and used to assist our project's conservation efforts. Thank you for contributing to the BeeCololgy Project!

Appendix E.3: Script for Introduction Video

Introduction Video

What would you say if I told you the number of species for one insect has been halved in the past twenty years in Massachusetts? Now before you start cheering, I'd ask you to hear me out in their defense. This is the humble bumblebee. Bumblebees are hard workers and they have a more important role in your life than you know! Bumblebees are one of nature's best pollinators, and are often used in pollinating popular greenhouse crops such as tomatoes, peppers, and cucumbers. Bumblebees also pollinate local wildflowers which supports a wide variety of local ecosystems. But it's important to note that the variety in species of bumblebees is what gives them such a wide reaching effect. Just because one species is seen frequently doesn't mean that the area's ecosystems are doing fine. And because bumblebees play such a keystone role in ecosystems, without greater numbers of diverse bumblebee species, expect a lot more endangered wildlife species in your own backyard. So to keep these all-important bumblebees around, we need your help.

The Beecology Project has developed a quick method for savvy citizen scientists like yourself to log bumblebees and the flowers they visit, working alongside ecologists across the state. Our Beecology web and Android apps allow you to identify the species of bumblebee from a screenshot using the color patterns on the bee's body. Click on our Bee ID video to learn more about how to take a good video and screenshot of a bumblebee. It's important that we get data from bee-cologists across the state into our database because the more data that we collect, the better picture we'll have about the distribution and ecological needs of different bumblebee species. We have tools to make the database easier to look at, and these tools will help us answer questions like "What species of flowers do certain bumblebee species prefer?", or "What time of year are certain bumblebees active while others are not?" Our computer model of bumblebee species can also help us answer questions like "What effect do pesticides or invasive species have on bumblebee populations?" more accurately with this data. If we can answer these questions and more, we can take action to diversify gardens flowers to be more bumblebee-friendly and propose other solutions about how to increase bumblebee species diversity to save our native species. And you will have played a big part in saving these all-important species.

In addition to solving the problem of bumblebee decline, the Beecology project is all about educating people about what you can do to help them. Our website has more in depth information about bumblebees in the

background tab if you want to learn more, along with videos to help you learn to use our apps. You can download our android app directly from the site as well. We encourage you to ask questions, since fellow Beecologists from all walks of life can share things like the best locations to find rare bees or the tips in gardening to accommodate more bumblebee species. And the prestige of finding a species no one else has gives ultimate bragging rights for your beecologist score. We hope you learn something new about bumblebees and appreciate the big role of such a little guy in your own life. Because the support from people like you can really make a difference. Happy hunting!

Appendix E.4: Script for Bee Identification Tutorial

0:00 - In this video, we'll explain how to take good, clear videos of bees and flowers, as well as the sort of physical characteristics that you'll be looking for when you identify a bee. Regardless if you're using the web app or the mobile app, this video will help you get the best results from your bee hunting. But before we get to snapping pictures, we need a quick lesson on bumblebee anatomy.

0: 30 - Bumblebees, unlike some of their honeybee and wasp relatives, have hair covering each of the three segments of their bodies (the head, thorax, and abdomen). This gives their bodies a complete fuzzy appearance. For comparison, wasps and yellow-jackets are completely hairless, and European honeybees (the only species in North America) have hair on their heads and thoraxes, so make sure not to confuse bumblebees with them.

1:00 - Once you've identified your bumblebee, you're ready to take your video. Make sure to keep your recording device between 6 and 12 inches away from the bee, keeping it in focus while you hold the device steady. Don't worry if you can't get it the first couple of times, it may take a few tries to get used to filming. Bumble bees can move around quickly, and there may be wind or other disturbances that can make getting a clear shot difficult. It is best to film the bee while it is on a flower collecting nectar or pollen, since it's relatively stationary. Make sure you get views from the top and sides if possible, since you will be identifying the bee species using coloration on the head, thorax, and abdomen. Finally, if at all possible, do not zoom in while taking the video of the bee. It is much easier to keep the bee in frame if you move closer to it rather than zooming. It could save your phone from being thrown onto the pavement or in a nearby lake in frustration.

1:50 - As some additional points, make sure to record your location and get a good shot of the flower in the video. Location is an integral part of the bee identification process and in the web application, flower data will be used to help identify the bee species. If the flower is not in frame for the video, take a picture of it afterwards. For the final question in the questionnaire, you will be asked if the bee is collecting nectar or pollen. You can tell if a bee is collecting nectar if it climbs inside a tubed flower, or if it sits in the middle of a flat flower using its tongue to probe for nectar. You can tell if the bee is collecting pollen if it makes a distinct buzzing sound and moves around the flower. And if you are still not sure from your video, no worries. There's an option for "not sure" too.

2:00 - The next two videos will show you the processes for taking your videos and screenshots, since they differ between Apple products and Androids. Click the video that matches your device and best of luck in your bee hunting!

Video title subsections:

- Stability
- Zoom
- Perspective(bee)
- Physical Attributes(bee)
- Physical Attributes(flower)(we want photos/clips for this and the above section)
- We also want video of someone actually taking pictures in the field for this tutorial

Stability:

0:20 - Hold your camera or phone steady. Bumble bees can move around quickly, and there may be wind or other disturbances that can make getting a clear shot difficult. If you have an android device and are taking a video, you can use the Google Photos 'Stabilization' feature to stabilize your shots after you've taken them.

Zoom:
0:40 - Bees are small; to identify the color patterns on the head, thorax, and abdomen you'll want to be a distance of 1-3 feet from the bee, or zoom enough to see these features. Note that if you're using an android device, then the zoom function on the camera is a 'soft zoom', this means it doesn't actually adjust the lense of your camera, and only expands the image taken. A point-and-shoot or other standalone camera likely has 'hard zoom' capabilities, which will produce much more accurately zoomed footage.

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