INSECT IDENTIFICATION

THROUGH CITIZEN SCIENCE

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Abstract

Artificial Light at Night (ALAN), or light pollution, is increasingly prominent in modern society. Many scientists suspect that ALAN is a cause of the decline of the insect population. To understand it further, it is necessary to acquire data on the specific insects attracted to the streetlights. Working with the Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB), we created a dichotomous key for insect identification. Using this key, we developed an interactive mobile and desktop application for citizen scientists. We then conducted three rounds of user testing to improve upon the accuracy and efficiency of both the dichotomous key and the applications. Afterwards, we integrated a data entry feature for the professional scientists to digitize and simplify their entry process. Using our applications, the AuBe project at the IGB will be able to identify insect orders much more efficiently, thereby collecting more of the necessary data. This data will enable scientists to conduct a comparative study to test their hypothesis about the relative importance of ALAN to insect health.

Insect traps on street lamps. | Image Credit: Sophia Dehn/IGB
Cover page | Image Credit: Levon Biss [39]

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Insect Identification Through Citizen Science:

An Investigation into Artificial Light at Night

Insects, which account for more than half of the animal species on earth, are facing an ecological crisis. As seen in Figure 1, the total global insect population has declined 41% over the past decade. Insects play a crucial role in the food chain and balance the ecosystem since they are the essential nutrient source of a tremendous number of terrestrial organisms and the vital component of aquatic ecosystems [1]. However, the abundance of Artificial Light At Night (ALAN) around the globe poses a rising concern about the possible consequences for nocturnally active insects' critical behaviors, such as foraging, migration and dispersion, predator avoidance, and reproduction [2]. The disruption of these essential behaviors causes mortality in many insects [3]. If those populations were to decline significantly, the broad ecological impact would be felt throughout Europe.

Many species relying on insects for their food source would see a population decline, causing further implications for insect diversity and ecological problems on a global scale [4]. Because of this, it is increasingly important to protect insect populations, which can be done by studying one of the possible causes of their decline: Artificial Light At Night.

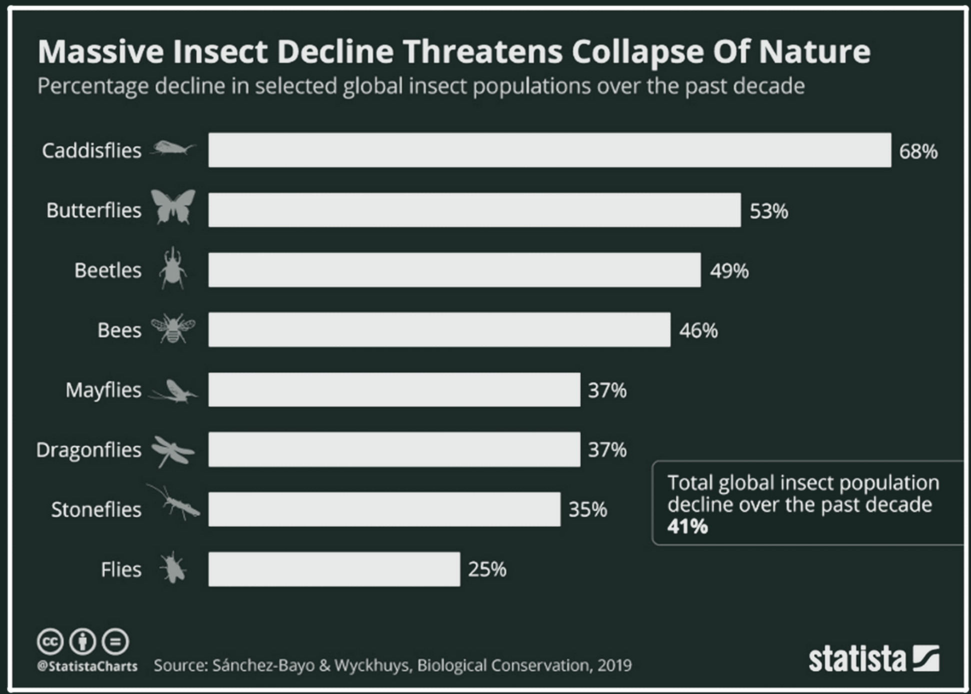


Figure 1: Evidence for the decline of the insect population [5]

In order to better study ALAN's impact on insects, scientists need to employ new methods. Since automated insect identification is not yet possible [6], it is necessary to identify insects one-by-one. This process is arduous and time-consuming for scientists. To aid them in amassing larger data sets, it is essential to recruit more participants in the research process. Citizen science is a scientific research method in which the non-professional citizens partner with professional scientists to "collectively gather, submit, or analyze large quantities of data" [7]. By engaging citizens in the identification process, scientists are able to promote scientific literacy and disseminate the import of their research to a broader audience [8] [9].

For our project, we worked with the Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB) to design a desktop and mobile application for citizen scientists to identify insects and for professional scientists to enter insect data into a database. More specifically, we

(1) implemented a practical method of insect identification in an application for mobile and desktop,
(2) evaluated the system of identification, and
(3) digitized the data entry process for the professional scientists.

ALAN’s Impact on Insects

Insects are fundamental to all natural environments. They are an irreplaceable component of many food chains and maintain balance in the ecosystem. More specifically, flying insects are the primary food source of many bird species. Research in the Cariboo region of British Columbia, for example, shows a significant link between the population of damselflies and the chance of successfully raising a young yellow-headed blackbird [10]. Many commonly known mammals such as American anteaters, bats, and shrews also seek insects as their primary food source. Black bears, for example, use ants to quickly gather nutrients like protein and amino acids, which are challenging to obtain from other food sources in the spring [11].

Beyond their significance to the ecosystem, insects are essential to human beings. The declining insect population will significantly impact agriculture. The decreasing honeybee population has raised public concern because honey is an essential source of sweetness in our food, and the bees are crucial pollinators to fertilize crops. Insects also facilitate returning nutrients to the soil by decomposing dead animals and plants to fertilize the growing crop [12]. Therefore the ecological changes caused by the insect population decline would in turn create significant impacts on humans as well.

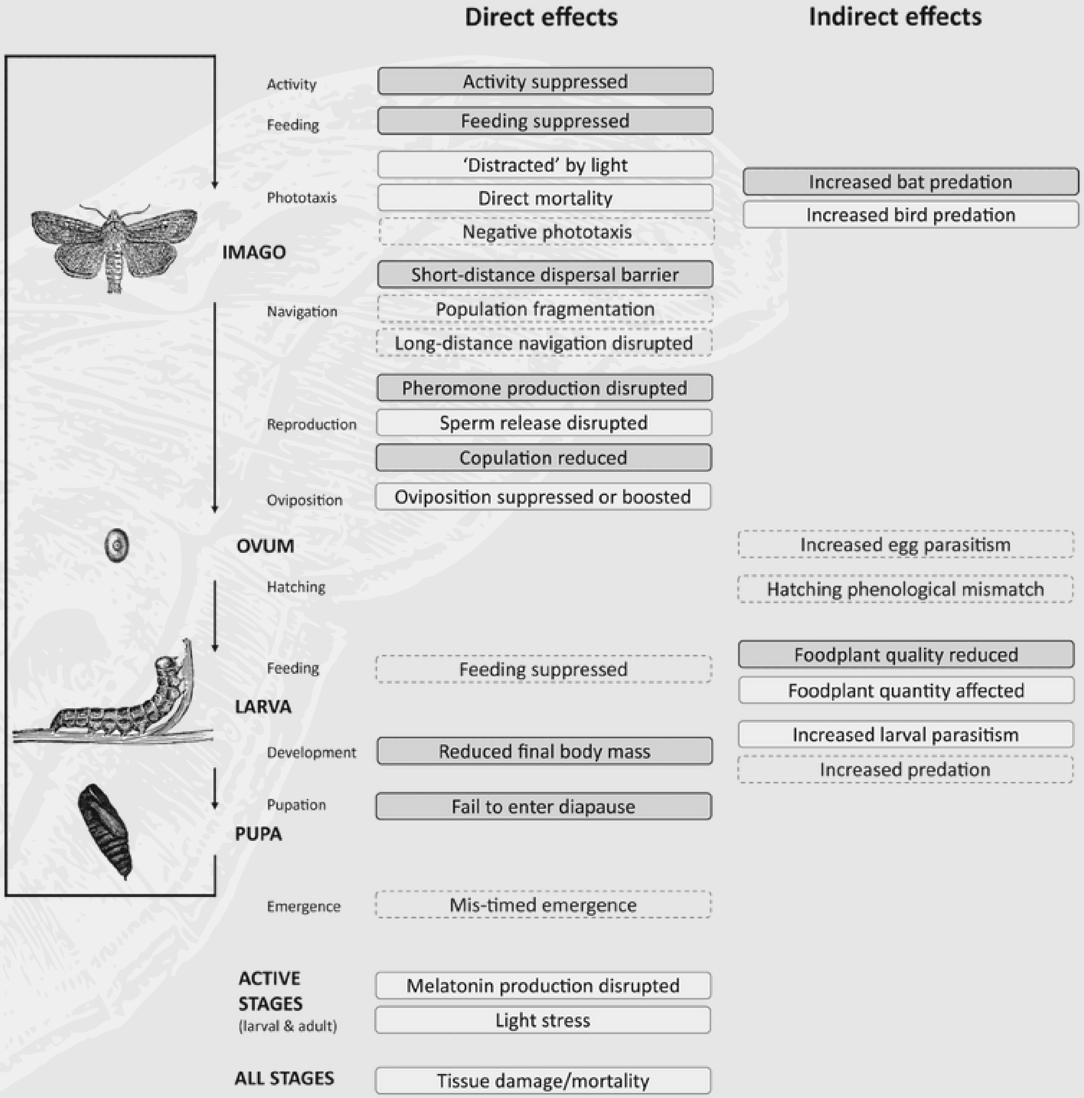


Figure 2: Evidence for effects from artificial light on moths across the life cycle [16].

However, the insect population has been experiencing a rapid decline in the last decade, and artificial lights are a possible cause. Many biologists are concerned that artificial lights negatively affect nocturnal insects' critical behaviors, such as foraging, migration and dispersion, predator avoidance, and reproduction, which may have wider implications on the ecological environment as a whole [13]. Figure 2 shows the direct and indirect implications that ALAN has on moths, exemplifying the numerous negative consequences of ALAN on insects. Unfortunately, the public currently has limited knowledge on insects [14] and low awareness of insect conservation [15].

Fly-to-light behavior makes the insect community vulnerable under artificial illumination [17]. The artificial illumination “traps” insects around it, causing mass insect mortality. This additional light supersedes the insects’ naturally occurring luminescence used for communication and reproduction. Another example of this disturbance can be seen when looking at the parasitoid Venturia canescens. This species of wasp is usually dormant at night, but they can become active even at deficient levels of ALAN. This change leads to impacted diurnal (daytime) activity patterns, consisting of a shift from active reproduction to greater feeding activity. Furthermore, increased predation of other animals on these insects is also an effect caused by ALAN.

According to a study conducted by Manfrin, “The abundance of several night-active ground-dwelling predators (Pachygnatha clercki, Trochosa sp., Opiliones) increased under ALAN and their activity was extended into the day” [18]. Holzhauer et al. additionally concluded that changes in insect patterns due to artificial lighting make it easier for predators to raze insect populations quickly. Insects are attracted to light sources which creates a gathering of prey and a consistent and reliable source of food, affecting the natural flow of food in the surrounding environment.

Currently, only a limited amount of research on the short-term impact of ALAN has been studied, and more research on the long-term impact of artificial light at night on insects is urgently needed in order fully understand the extent of ALAN’s impact on the insect population [19].

Figure 3: Streetlight with shutters [23].

Much scientific research has focused on streetlight design for its potential to reduce the adverse impact on insects. Schroer et al. provided a solution that streetlights should only emit light where it is needed by using shutters (an example can be found in Figure 3); the light will not be visible from adjacent water bodies, floodplains, or other habitats [20]. Other scientists recommend “avoiding metal halide light installations as they attract more insects than competing technologies” [21]. Specifically, they discuss the need to “tailor LED lighting to prevent disturbances across multiple insect taxa” [22]. To this end, the IGB created their Artenschutz durch umweltverträgliche Beleuchtung (AuBe) project, aiming to develop environmentally friendly streetlights that minimize ALAN’s adverse impacts on insects.

In order to design insect-friendly streetlights, more data on ALAN's adverse impacts on insects is needed. Traditional science that is conducted with exclusively professional scientists is insufficient in this context due to the mass quantity of data across different locations needed for the research. Since the scientists at the IGB wish to collect data on a large quantity of insects of multitude orders across Germany [24] (these locations are shown in Figure 4), it is more efficient and cost-effective to employ volunteer citizen scientists who are able to collect more precise data across a large region. In fact, citizen science is a well-employed tool in ecological research. Dickinson et al., for example, commented that "citizen science accounts for growth in the fields of macroecology and geographical ecology" by "allowing ecologists to move from local inference to inference at the scale of species ranges and ecosystems" [25].

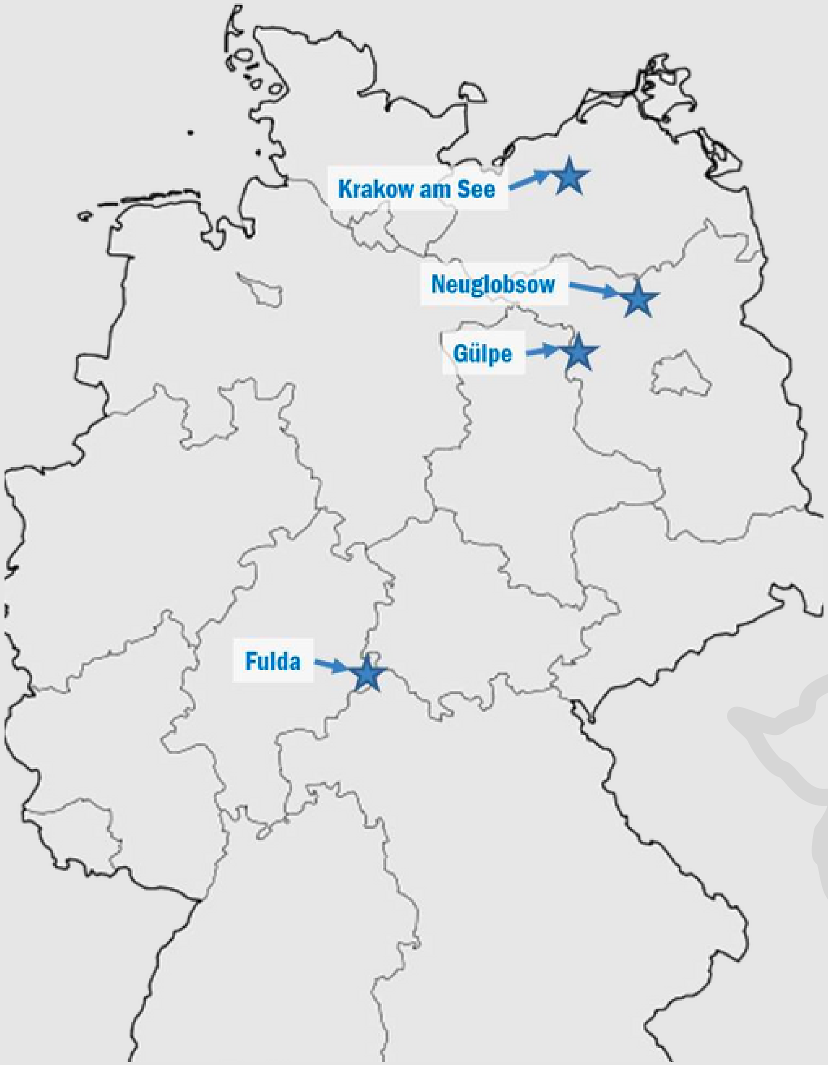


Figure 4: Locations of Insect Collection for the AuBe Project [26].

The Role of Citizen Science in ALAN Research

Citizen science is uniquely positioned to fill a lacuna in entomologists' understanding of how ALAN affects insects: namely, data availability.

In a study done in 2021, the scientists analyzing this problem included a disclaimer saying: "Perhaps the biggest future challenge in this field is to assess whether the many documented impacts of ALAN on individual insects have any detectable effects over longer time scales on the dynamics of populations, communities and ecosystems" [27]. This observation addresses the core problem: It is easy to study the impact on individual insects, however, extrapolating that to a greater population is challenging. A considerable factor in this lack of research is tied to the limited availability of data on insect populations. Citizen science mitigates this problem since it can collect a large amount of data over extensive geographical areas.

Dickinson et al. analyzed the example of Project FeederWatch, a volunteer-based project that aims to collect data on "winter bird abundance and distribution" by participants across the US and Canada [28].

From 2008 to 2009, project FeederWatch received 1,342,633 observations. As shown in the map in Figure 5, the blue dots represent the location of the participants who observed the birds [30]. This project collects massive amounts of data that are impossible to gather by small teams of professional scientists. In general, citizen science is a cost-efficient way to utilize the general public to conduct scientific research due to its ability to recruit volunteers for data collection.

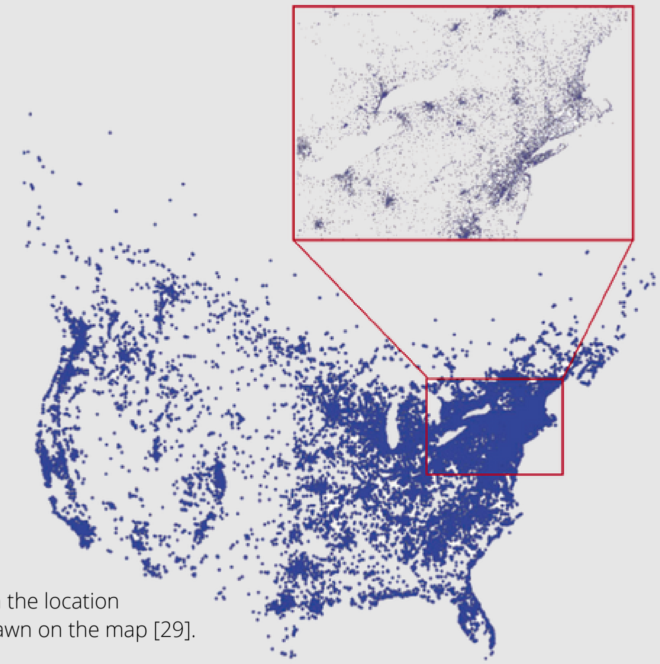
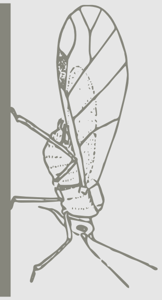


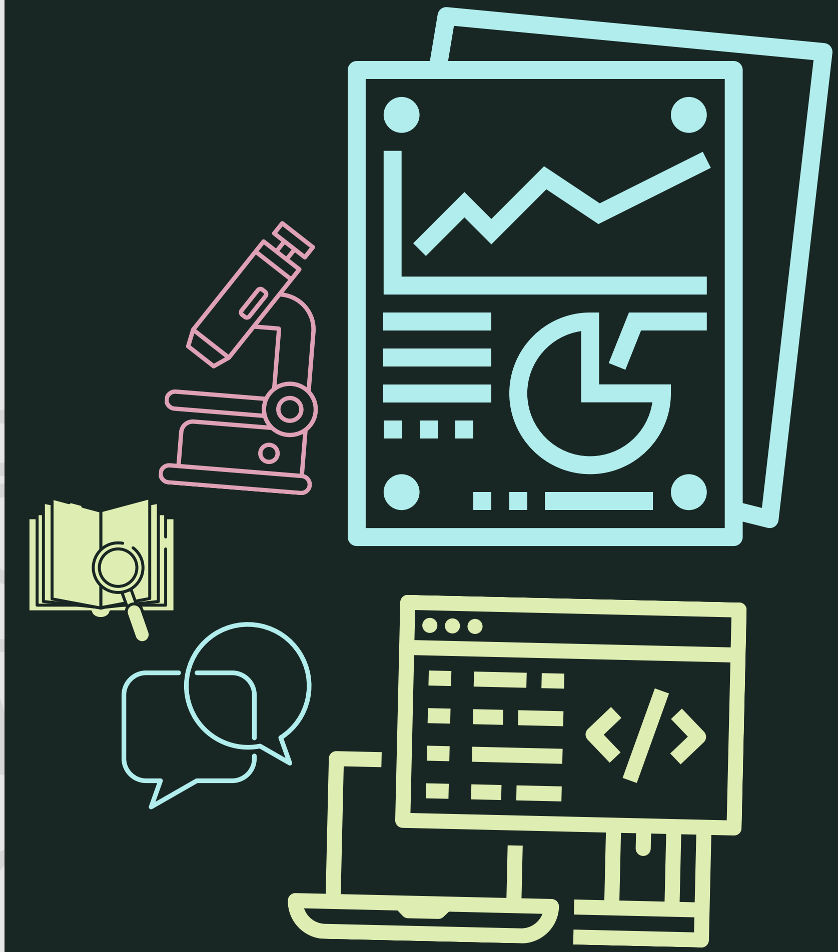
Figure 5:
FeederWatch with the location
of participants drawn on the map [29].

Besides its efficacy in achieving large data sets, citizen science is an appealing method because it advances science while promoting citizens' knowledge and awareness of science. Citizen science is a scientific research method in which non-professional citizens partner with professional scientists to "collectively gather, submit, or analyze large quantities of data" [31]. It aims to create a positive social impact by promoting participants' interest and awareness in science. In a study by Crall, et al., researchers have tested participants on their knowledge of invasive species after their participation in a research study using citizen science [32]. Through experiments, researchers discovered that these participants showed "small increases in content knowledge of invasive species, global positioning system (GPS), and vegetation monitoring when using context-specific measures" [33]. Jordan et al. found that hikers who were trained in collecting data about invasive plants reported an increase in the ability to recognize invasive plants [34]. Furthermore, the authors also reported an increased awareness of the impact of invasive plants on the environment [35].

For these reasons, citizen science would be an effective method to employ in the IGB's research. To quantify the impact of ALAN on the insects, the IGB needs to identify the insects near the streelights in Berlin. Citizen science can achieve this through the large quantity of data that volunteers collect. Furthermore, citizen science also promotes scientific literacy as well as participation in science. In short, citizen science benefits both the professional scientists and the citizen scientists, thus creating advancements in both communities.



Method & Results



Our Development Process

1

IMPLEMENT

a practical method for insect identification in an application

2

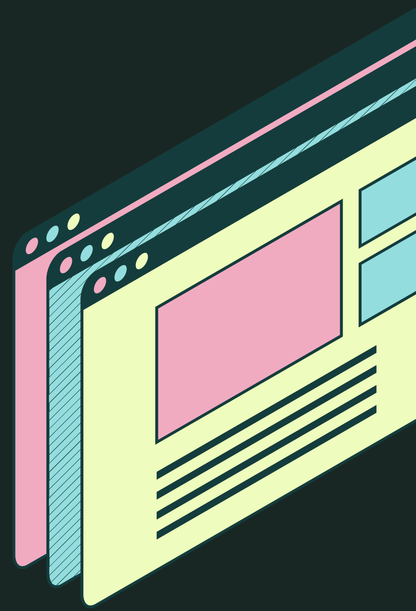
EVALUATE

the system of identification

3

DIGITIZE

the data entry process for professional scientists



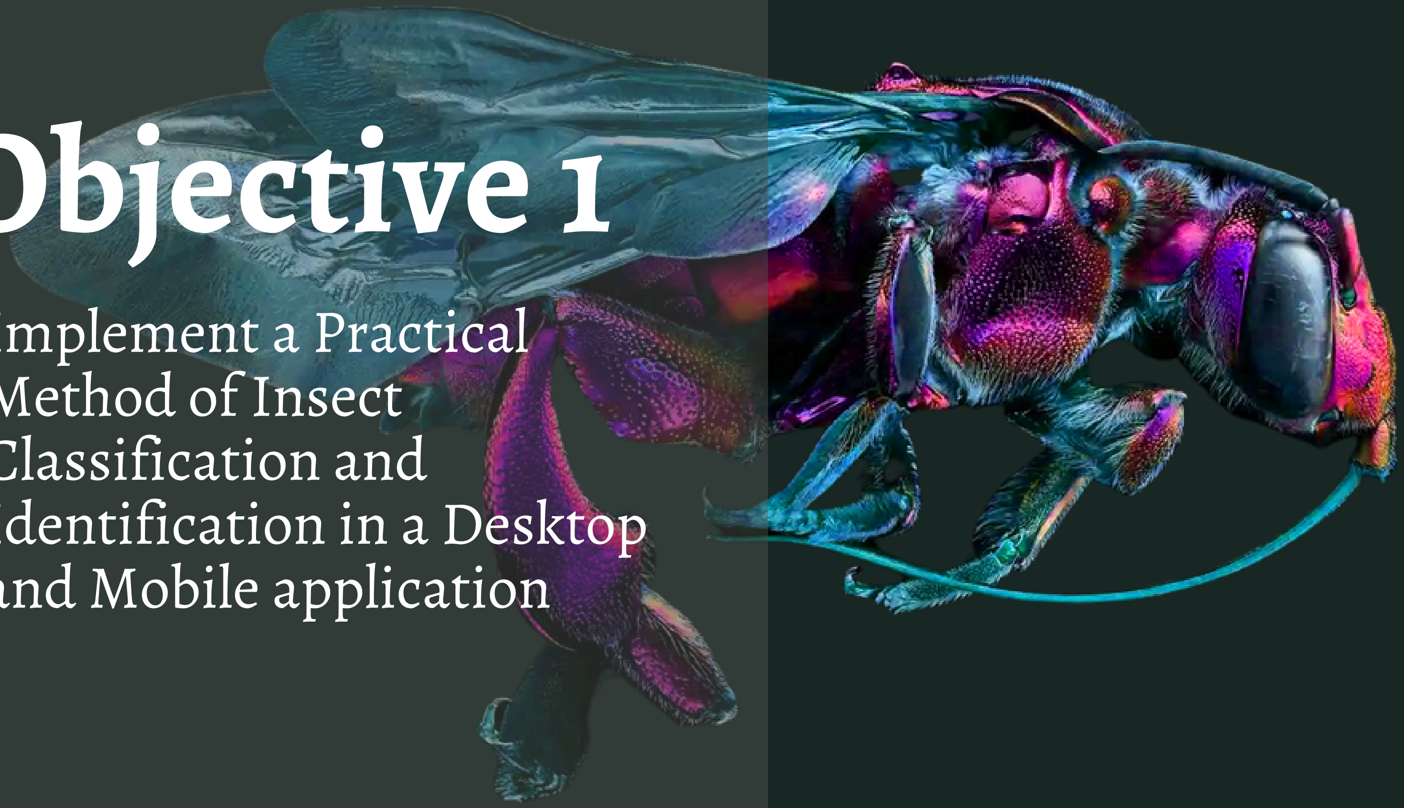
This project sought to design a desktop and mobile application for citizen scientists to identify insects and for professional scientists to enter insect data into a database. This provided data for the IGB to design effective streetlamp coverings that reduce the harm of artificial lighting to local insect populations. The project had three subsidiary objectives:

(1) implement a practical method of insect classification and identification in a desktop and mobile application,
(2) evaluate the system of identification, and
(3) digitize the data entry process for the professional scientists.

A detailed flowchart of our methods can be found in Appendix H.

Objective 1

Implement a Practical Method of Insect Classification and Identification in a Desktop and Mobile application



1.1 Experiential Learning in Insect Identification

We started by engaging in experiential learning at the IGB (Figure 6). We used a sample dichotomous key to identify the insects using a microscope under the supervision of an entomologist. We identified around ten insects total and experienced the identification process first-hand as nonprofessionals. We wrote down the difficulties encountered during the process.

Figure 6: Identifying insects at the IGB.

The experiential learning pinpointed the difficulties of mass insect identification due to the damage incurred by the preservation process and storage conditions after collection. This damage was mainly observed in three areas: a loss of color, bent or damaged wings and appendages, and broken or missing body parts. First, we noted that all the insects were colorless due to desaturation from the ethanol preservation solution; thus it was unhelpful to ask identification questions involving color. Similarly, some insects were preserved with their wings spread out, making them impossible to identify using questions involving wing positions, such as "wings held roof-like over the body". Furthermore, the sample identification key was confusing due to an overuse of jargon, the imprecision of wording, and the lack of pictures. We kept this in mind when developing the key by including pictures and specifying information such as the length of antennae.

The experiential learning also enabled us to develop practical instructions for user testing. We observed that it was difficult to view an entire sample at high resolution using the microscope, requiring a long time to adjust to distance and focus, which could potentially lead to user errors during identification. Thus, we planned to give the citizen scientists a tutorial on how to use the microscope prior to each identification test. We also observed that the hindwings of many insects were hidden under their front wings, requiring the user to flip the insects to see them clearly. Because of this, we planned to guide the citizen scientists during user testing by reminding them of such information to minimize user error.

1.2 Secondary Research on Dichotomous Keys

We conducted secondary research on scientific papers and books published on insect taxonomy. Specifically, we reviewed the existing dichotomous keys of insect orders and cross-compared them to ensure that they are correct and up to date, since taxonomy is fluid and often changes with time. We aimed to identify 24 insects up to order (Appendix C).

Name	Mouthpart	Texture of Wing		
Coleoptera	chewing	shell like	no cerci	
Dytiscidae	chewing	shell like	no cerci	oval shape
Dermaptera	chewing	shell like	cerci	

Name	Mouthpart	Texture of Wing	Hair on the wing	Comparison of FW to HW	Appendages	
Hymenoptera	chewing	not shell like	no	FW is slightly larger	short or no cerci	>3 segments of tarsi
Psocoptera	chewing	not shell like	no	FW is slightly larger	short or no cerci	2-3 segments of tarsi
Ephemeroptera	chewing/reduced	not shell like	no	FW is significantly larger	long cerci	
Orthoptera	chewing	not shell like	no	HW is broader than FW		
Megaloptera	chewing	not shell like	no	same size	Long Antenna	no ternimal branching wing veins
Neuroptera	chewing	not shell like	no	same size/FW larger	Long Antenna	has terminal branching wing veins
Odonata	chewing	not shell like	no	same size/HW larger	Short Antenna	

Name	Mouthpart	Texture of Wing	Hair on the wing	Antenna		
Trichoptera	chewing/reduced	not shell like	yes			
Micro Lepidopter	hard to tell	not shell like	yes			
Thysanoptera	hard to tell	not shell like	yes			

Lepidoptera	coiled

Name	Mouthpart	00 Number of Wi	Antenna
Diptera	piercing	1	Short or absent
Brachycera	piercing	1	Short or absent
Nematocera	piercing	1	Long
Hemiptera	piercing	2	
Auchenorrhynch:	piercing	2	
Heteroptera	piercing	2	
Sternorrhyncha	piercing	2	longer than head

Figure 7: Table of Insect Characteristics.

By conducting secondary research on the existing dichotomous keys, we improved the efficiency of the first draft of our key. An efficient dichotomous key reduces the total amount of possible answers in half with each question it asks. Cross-comparing the existing keys allowed us to create a table of the characteristics of all 24 orders of insects (Figure 7), from which we were able to sort the priority of the questions using the commonalities of characteristics. This simplified the identification process for the users. Furthermore, the secondary research ensured that our dichotomous key was up to date and contained minimal wrong information at this stage.

1.3 Interviews with Entomologists

After we designed an appropriate draft of the dichotomous key, we conducted interviews with two entomologists at the IGB to receive feedback. Prior to the interviews we sent a draft of our working dichotomous key to give the scientists time to review before our interview. The interviews took the form of dialogue. Two team members, Jessica and Weizhe, were present for these interviews. They started by discussing the layout of the key, followed by the expert breaking down a list of any obvious errors they noticed. As each error was discussed, possible fixes, improvements, or corrections were noted for later revision. Lastly, the expert was provided time for a wide-scope conversation about further improvements and general changes. We chose to interview experts at the IGB because they had not only extensive knowledge regarding insect identification, but also substantial experiences in the AuBe project, which allowed them to provide valuable feedback in the context of ALAN.

The interviews ensured the accuracy of our key and accelerated the research process. Some specific information, such as the differences between aquatic and terrestrial *heteroptera*, were difficult to find using literature review. Asking specific questions as such during the interview with the entomologists accelerated the research process. Furthermore, the entomologists provided us specific feedback on the parts of the key that were factually false. For example, we mistakenly thought that *diptera* had two pairs of wings, whereas in actuality it always only has one pair. A picture of the feedback can be seen in Figure 8. Since we were not professional insect biologists, it was helpful to have a professional to guide us through the research process.

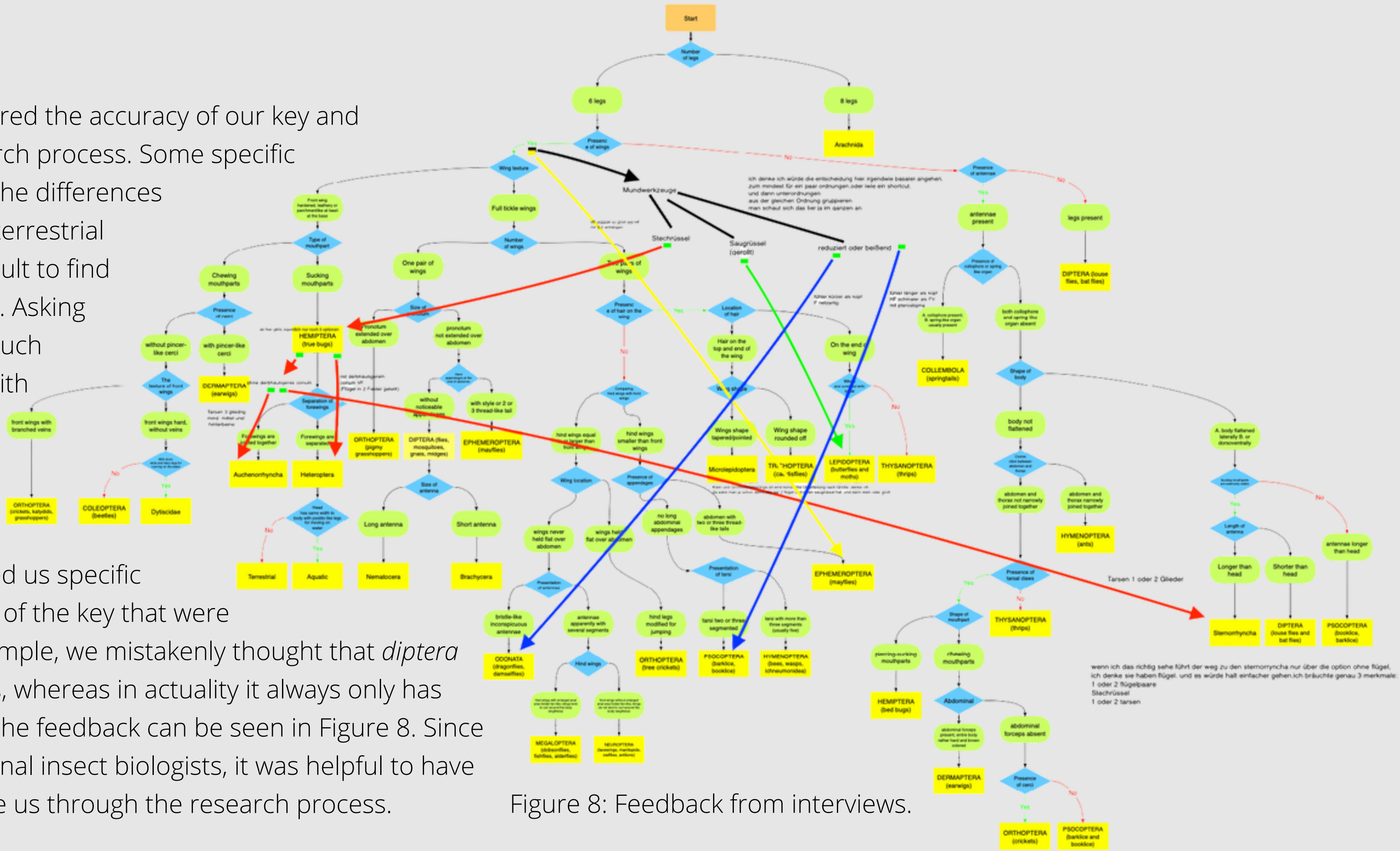


Figure 8: Feedback from interviews.

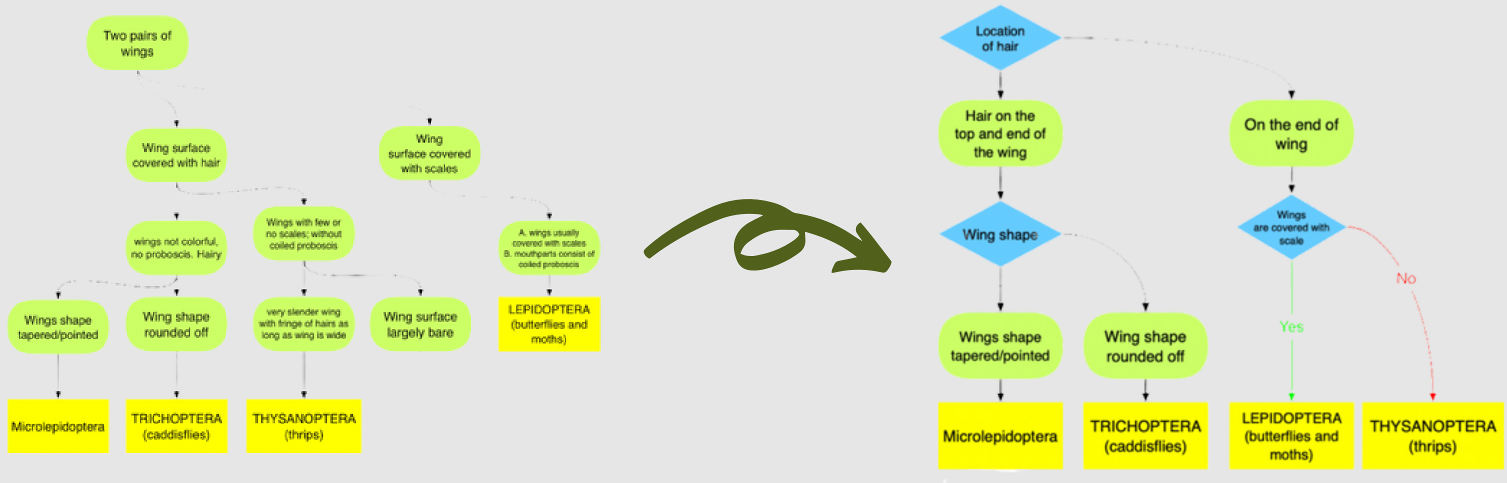
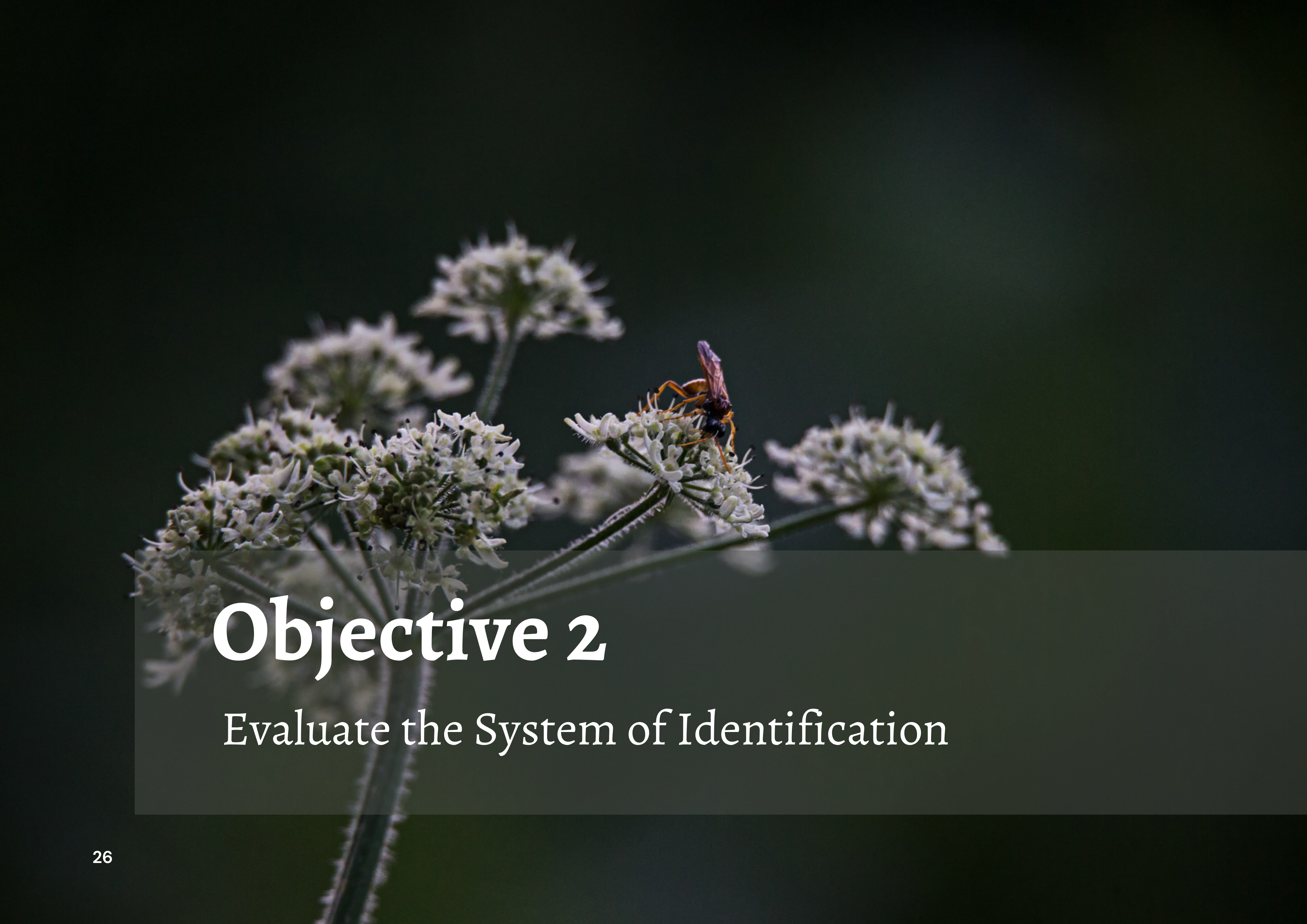


Figure 9: Our dichotomous key before and after revision.

The interviews also enabled us to simplify the logic of our key. Many parts of our key were factually correct but overly complicated. For example, we received suggestions on the classification of *lepidoptera, microlepidoptera, trichoptera, thysanoptera*. Instead of asking four questions and having ten information boxes, we reduced them to two questions and seven information boxes. Figure 9 shows our dichotomous key before and after revision from the feedback.

Using the feedback from the interviews, we improved our dichotomous key and developed a final draft (Appendix I). Our sponsors, Sarah Kimmig and Sophia Kiefer, translated it into German for the citizen scientists.

Using the dichotomous key, we developed a desktop and a mobile application so that the citizen scientists could interact with the key and see the pictures clearly.



Objective 2

Evaluate the System of Identification

For our second objective we evaluated our application through user testing. The evaluation process iterated three times: the first round focused on the data credibility and accuracy using the dichotomous key; the second round improved the precision of the insect identification process and optimized functionality; the last round refined the user experience and interface, ensuring that we finish with a final, polished application.

2.1 User Testing Round 1

First, we conducted user testing with seven citizen scientists to ensure the accuracy of the dichotomous key. We observed three of them in person at IGB Berlin (Figure 10), and the rest were done at other IGB locations with local coordinators. For the in-person tests, we observed the citizen scientists one-on-one as they used the dichotomous key.

Figure 10: Our team during user testing.

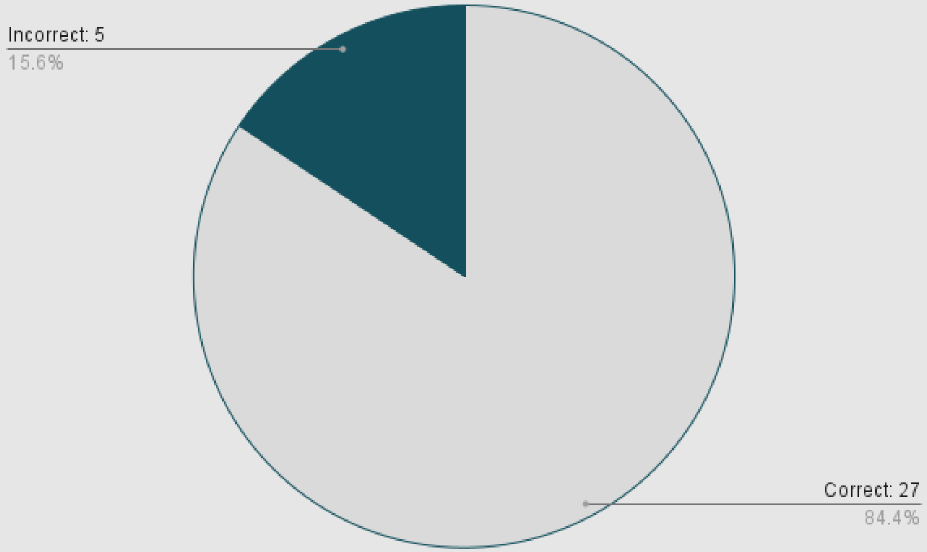


Figure 11: Results from user testing round 1.

With the help of an entomologist, we handed them the dichotomous key and provided 32 insects total to identify. Out of the 32 insects, 27 were identified correctly, giving a success rate of eighty-four percent (Figure 11). The citizen scientists were encouraged to use the think-aloud method and speak freely about their experience. We held two-way dialogues to identify the parts of the key that were difficult or confusing. We asked permission for voice recording and collected qualitative data in the form of transcripts. For the testing done remotely, we gathered their feedback by email via the local coordinators. We entered the issues the users encountered into a table (Appendix D).

This round of user testing improved the accuracy, efficiency, and clarity of our dichotomous key. The biggest issue discovered from this round of user testing was the misclassification of *diptera* (which includes suborders *nematocera* and *brachycera*). All four *diptera* samples were misclassified, uncovering the inaccuracy of our key on the categorization of mouthparts. Unlike what we thought, *diptera* have sponging/absorbing mouthparts, not piercing-sucking mouthparts. To resolve this, we added the option sponging/absorbing mouthparts, alongside pictures of insect mouth anatomy. We also added the picture shown in Figure 12 to help users properly identify the mouthparts. We planned to test on *diptera* again during the second round of user testing to ensure the accuracy of our key.

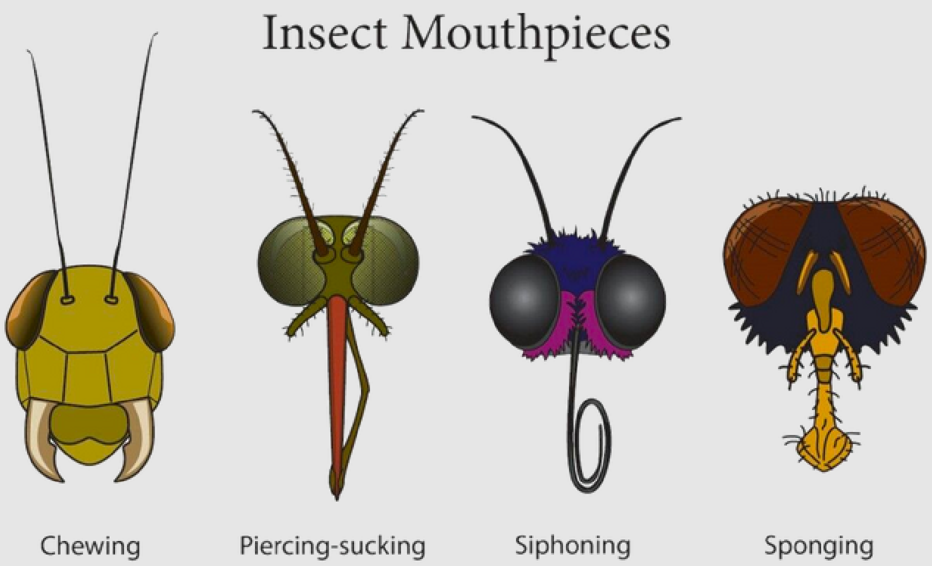


Figure 12: Categorization of insect mouthpieces [36].

We also observed that users were spending the most time on identifying body parts such as legs and mouthparts, which showed the inefficiency of our dichotomous key. Despite identifying the correct insect in the end, users often spent up to 5 minutes counting the number of legs or identifying the type of mouthparts in the process. This would lead to an unnecessary waste of time in research. To improve this, we reordered the questions in the key to maximize efficiency. Furthermore, we added specific pictures and sketches of insect body parts (e.g., thorax, abdomen etc.) so that the users could identify and categorize them efficiently.

Finally, we improved the clarity of our key by rewording the questions in the key. During user testing, we observed the users were sometimes confused due to the ambiguity of the questions. For example, one question asks “Are the antennae long or short?” One user misidentified *nematocera* for *brachycera* because the length of the antennae was ambiguous. To improve clarity, we changed this question to “Are the antennae longer or shorter than the head of the insect?” and added sketches to illustrate the length. We clarified wording for similar issues, a full list of which are shown in Appendix D.

2.2 User Testing Round 2

After revising our dichotomous key, we conducted interviews with eight citizen scientists at the IGB to ensure the accuracy of our key and the functionality of our applications. These citizen scientists are from the IGB and do not have a background in insect biology. We had four citizen scientists for the mobile application and four for the desktop application. We held four sessions, thirty minutes each. During each session, we asked one user to test for the mobile application and one user for the desktop application. For each user, one team member was giving instructions and answering questions, and the other was taking notes. To track feedback, we labeled each screen with a number (which we call insect ID) and wrote down the issue whenever the user asked a question about the insect, the identification key, or the application interface. We also took notes when the user misidentified the insect. A complete list of feedback can be found in Appendix E.

In total, the citizen scientists identified 20 out of 38 insects correctly. Due to the users' difficulty with identifying mouthparts, we simplified our dichotomous key further to minimize the emphasis on insect mouthparts. Despite our revisions from the last round of user testing, we observed that most, if not all, of the mistakes occurred due to the misidentification of the mouthparts. This was due to a combination of

(1) the lack of clarity in our dichotomous key,

(2) the user's lack of experience with the microscope, and

(3) the small size of the insect mouthpart.

However, we had already modified our key during the last iteration to improve (1), and we had little control over (2) and (3). Therefore, after consulting with the entomologist at the IGB, we decided to abandon the mouthpart as a key feature in the identification process. Instead, we reorganized the key to use features such as the texture of wings or the size of the wings to differentiate the insects. Our original key used the mouthpart to differentiate between 21 orders of insects, whereas our revised key used it to differentiate between only 5 orders of insects (Figure 13). Furthermore, instead of asking the users to be able to differentiate between piercing-sucking/absorbing, coiled, and chewing/reduced mouthparts, we now only ask them to differentiate between coiled and non-coiled mouthparts, thereby significantly reducing the possibility of user error.

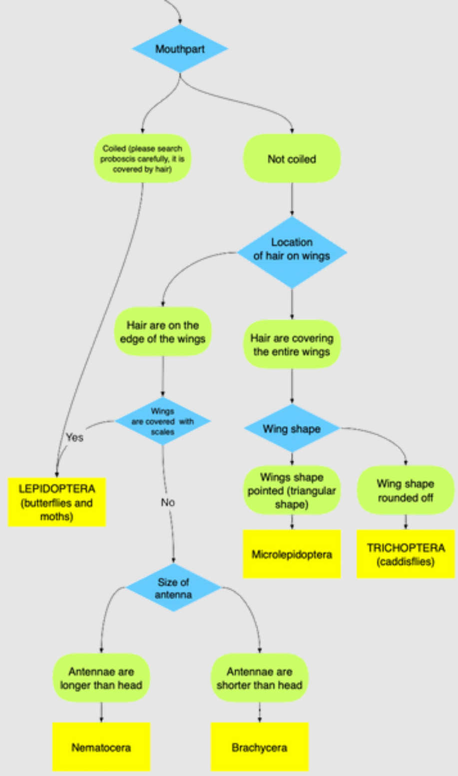


Figure 13: Identification logic of mouthpart after revision

We also revised the applications' user interface to improve user experience. We observed that many users had difficulty reading the descriptions on the desktop application due to the small font size, which caused frustration and inefficiency. We also noted that some users were confused with the layout in the mobile application due to the button placements. Other users were initially unaware that the mobile application could scroll, and therefore missed the buttons at the bottom of the screen. We revised the user interface according to these feedbacks and planned to test them during the next round of user testing.

2.3 User Testing Round 3

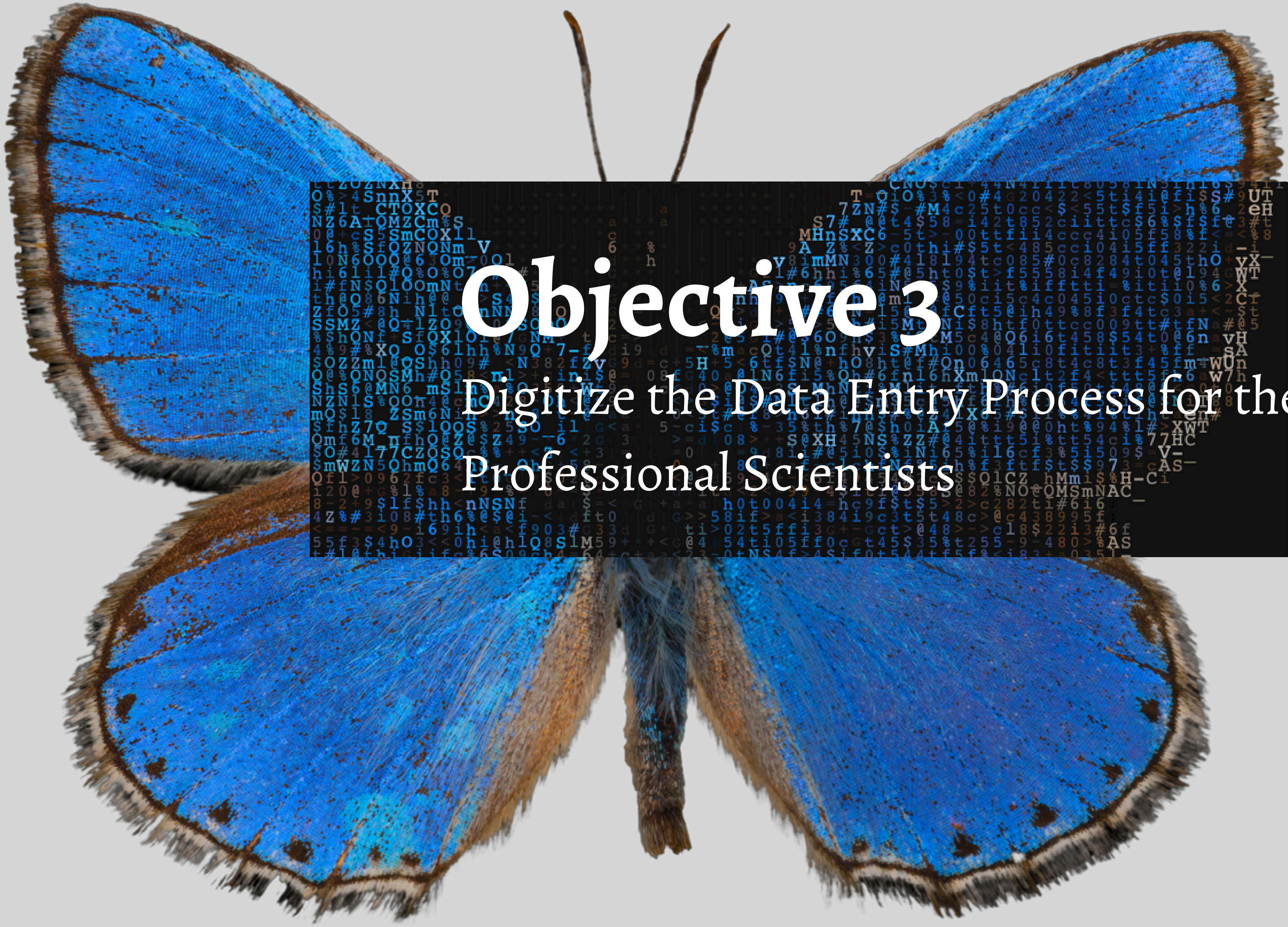
After revising the dichotomous key and the applications according to the last two rounds, we conducted our final round of user testing to ensure an accurate, functional, and aesthetic final product (Figure 14). We invited four citizen scientists to participate in this final round of user testing, two for each platform of our applications. We spent one hour with each user and collected qualitative feedback. We only selected four users because the goal of this last round was to emphasize the quality rather than the quantity of the feedback. We aimed to acquire in-depth feedback on the key's accuracy of specific insects and the general user experience.

Figure 14: User Testing round3

One of the goals of this round of user testing is to ensure the accuracy and efficiency of the key after the revision on mouthparts and user interface from last round. After carefully selecting 20 insects with different mouthparts, we were glad to find that our key had minimal errors. The users had no problem identifying the main features of the insects. In addition, the users had no problems with the user interface. Users understood the button placements without us needing to explain. One user remarked:

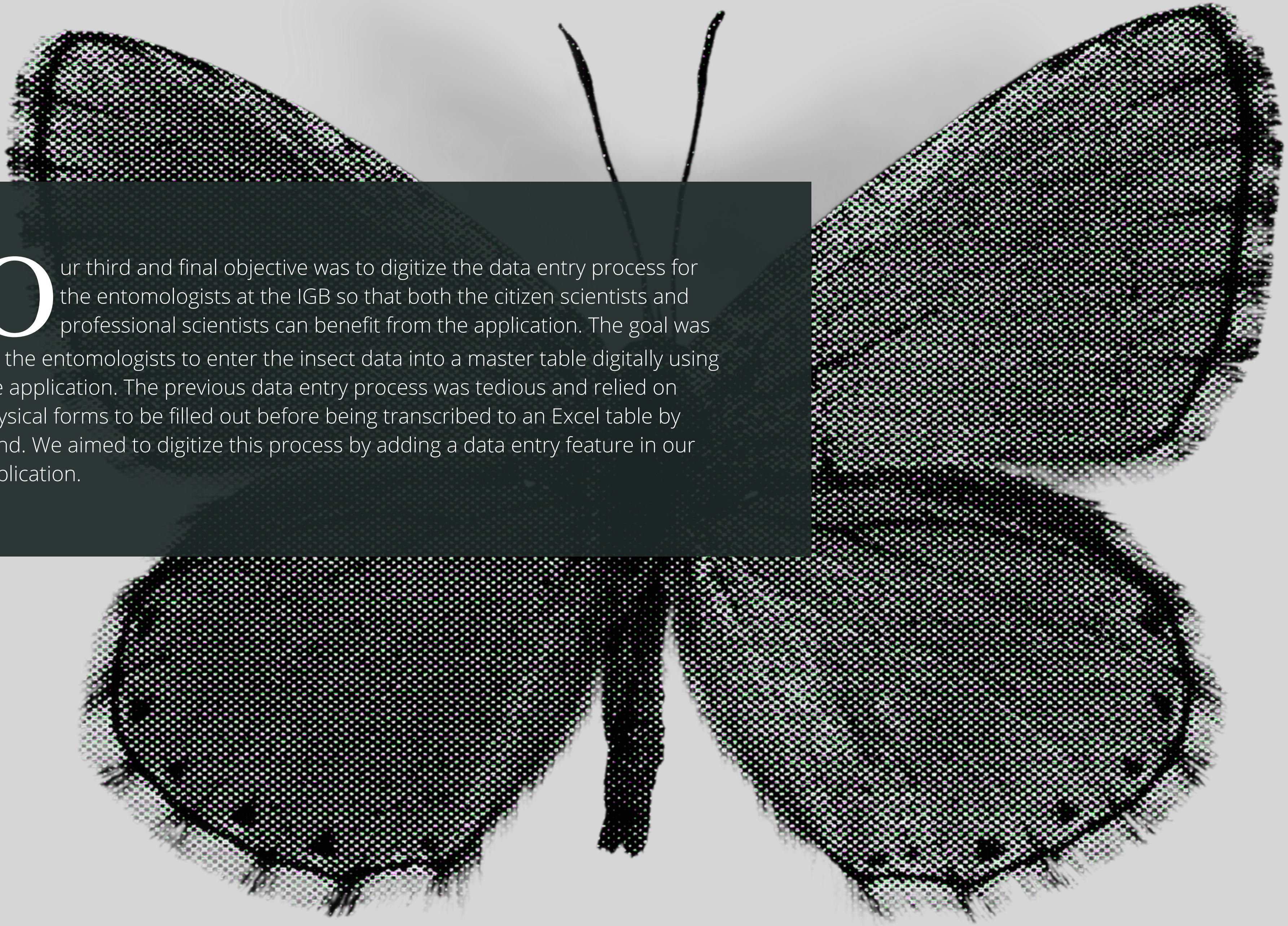
Most of the misidentifications in this round stemmed from the user's lack of expertise with microscopes. Since the users were citizen scientists without professional experiences in labs, they did not know how to manipulate the microscopes to best identify and classify the insect body parts. Before each session, we needed to teach the users how to zoom, focus, and adjust the back and overhead lights on the microscope. For example, if one question asked about the length of antennae and the next the number of segments of the legs, the user would need to zoom out of the antennae, move the petri dish to locate the legs, zoom in, change focus, and adjust the lighting to see clearly. Such skills could not be expected from first-time citizen scientists, and a lack of microscope skills led to an inefficient use of time and many misidentifications. To mitigate this issue, we created an instructional infographic (Figure 20) on how to use the microscope for accurate insect identification, which we implemented in the form of a tutorial in the applications.

> “The application interface is very intuitive to navigate!”



Objective 3

Digitize the Data Entry Process for the Professional Scientists



Our third and final objective was to digitize the data entry process for the entomologists at the IGB so that both the citizen scientists and professional scientists can benefit from the application. The goal was for the entomologists to enter the insect data into a master table digitally using the application. The previous data entry process was tedious and relied on physical forms to be filled out before being transcribed to an Excel table by hand. We aimed to digitize this process by adding a data entry feature in our application.

3.1 Interview for Requirement Collection

We started by conducting informal interviews with our two sponsors and two entomologists at the IGB to collect requirements. Requirement collection is an essential step in a software development lifecycle to ensure that we understand what the stakeholders are looking for. We learned the current data storage process and asked about the features they were looking for in the application. Specifically, we focused on the inputs that the users needed to enter into the application and the outputs that the scientists required in their database. From the interviews, we learned the two main requirements for the data entry feature: (1) ease of entry and (2) integration with the database.

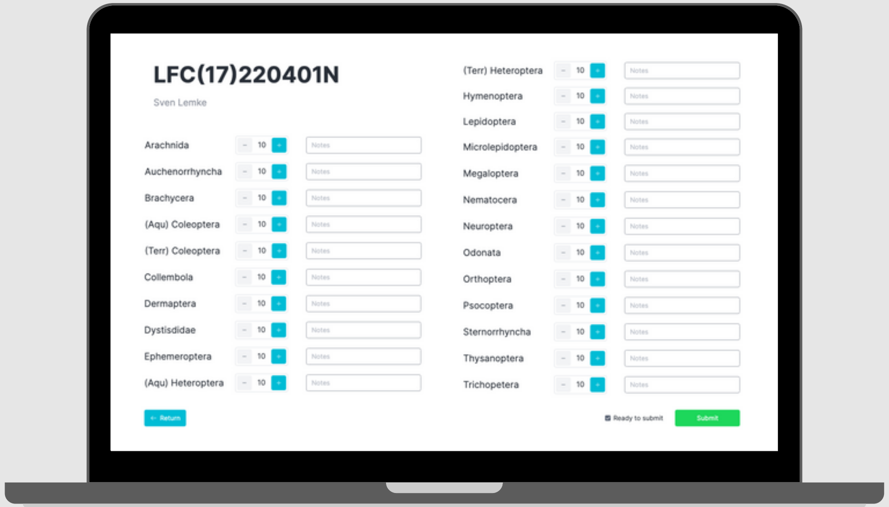


Figure 16: Digital Data Entry Mockup

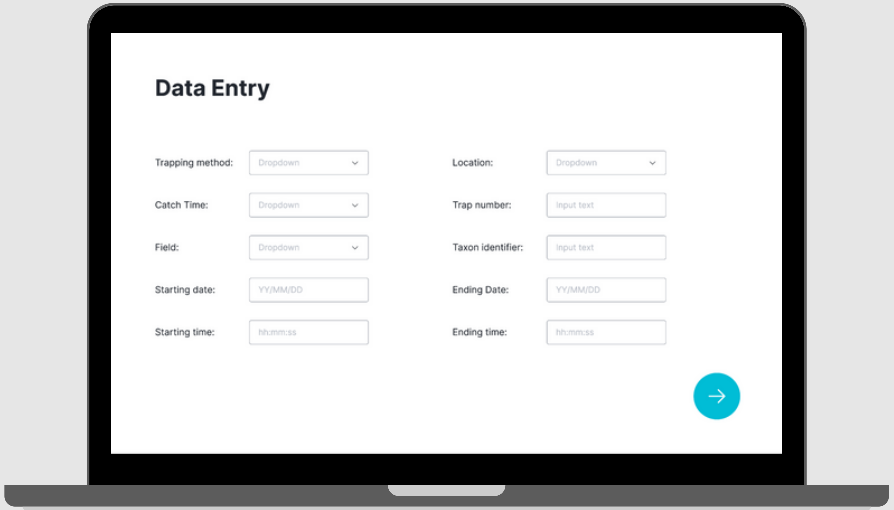
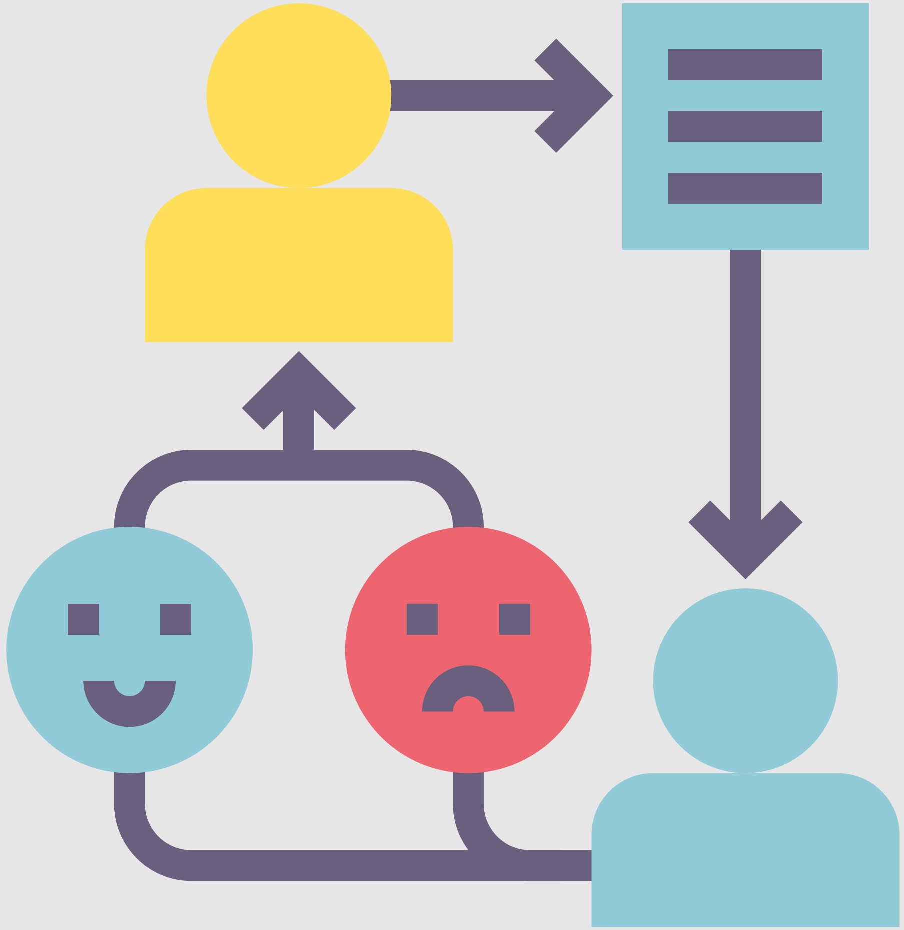


Figure 15: Digital Data Entry Mockup

One of the goals of this feature was to make the data entry process more efficient and easier for the professional scientists. We obtained the printed data sheet that the entomologists currently use (Appendix F) and acquired a list of information needed to be entered into the application. We clarified what each entry means and the options it requires, such as textboxes, drop-down menu, and date pickers. The second goal for the data entry feature was to ensure a seamless integration into the existing database. The IGB currently used a master Excel spreadsheet to manage with insect data, thus our application needed to be able to directly upload the entered data into this spreadsheet. We contacted the IT department to obtain access for their MySQL server. After collecting the requirements for the application, we created a design mockup (Figure 15 & 16) and received approval.

3.2 User Testing for Feedback

After completing a draft application with the data entry feature, we returned to the entomologists to perform a round of moderated user testing. During the testing, we asked the two entomologists to use the application to input insect data. We conducted the testing over zoom and observed their interaction with the application, noting down their points of confusion. We observed them using the application to classify insects, save data, and modify stored records in order to ensure the functionality of each part of our application. We collected notes and wrote down their responses in order to form a list of improvements (Appendix G). We then revised the application according to their feedback and formed a finalized version.



Final Outcomes and Deliverables

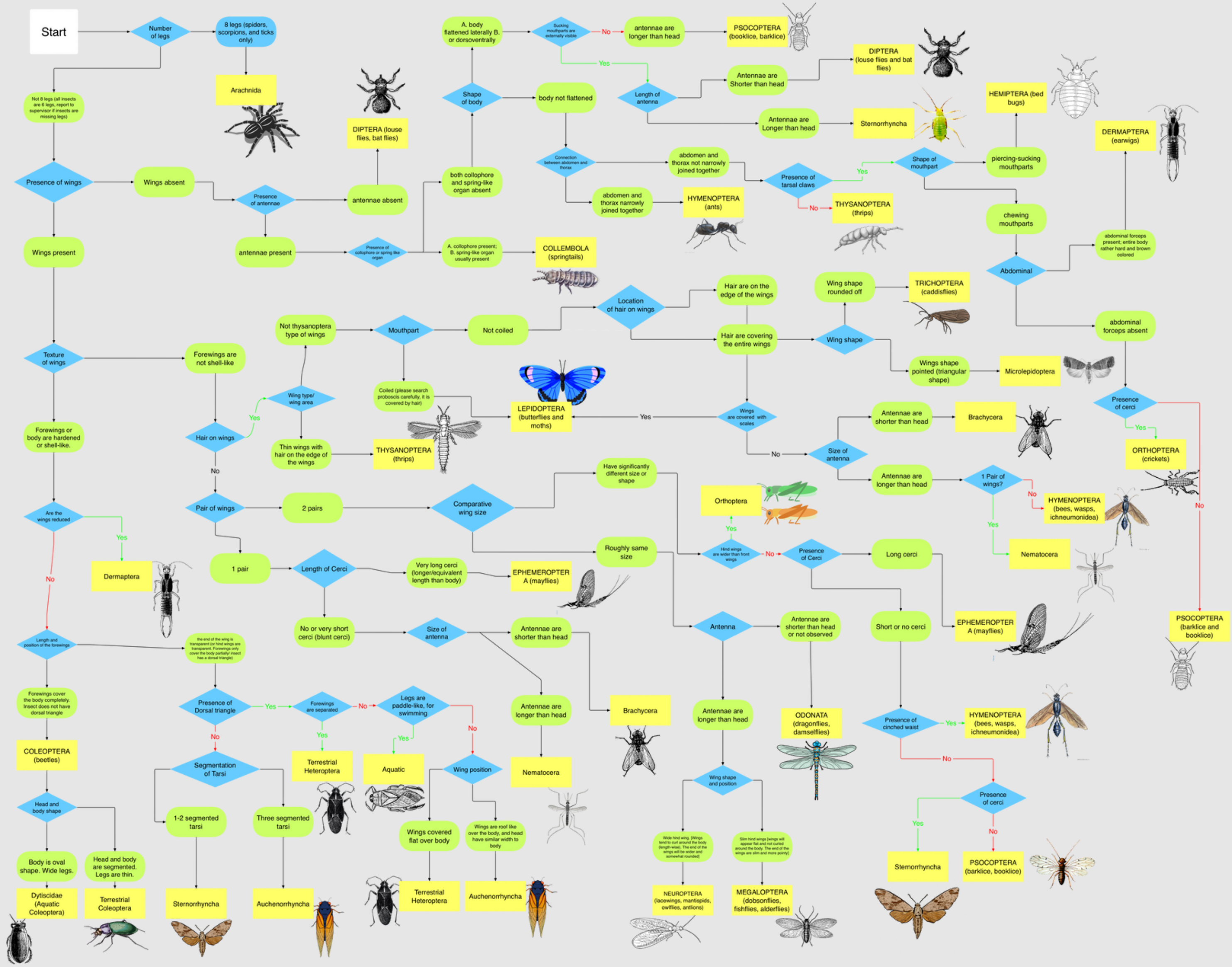


Figure 17: The finalized dichotomous key.

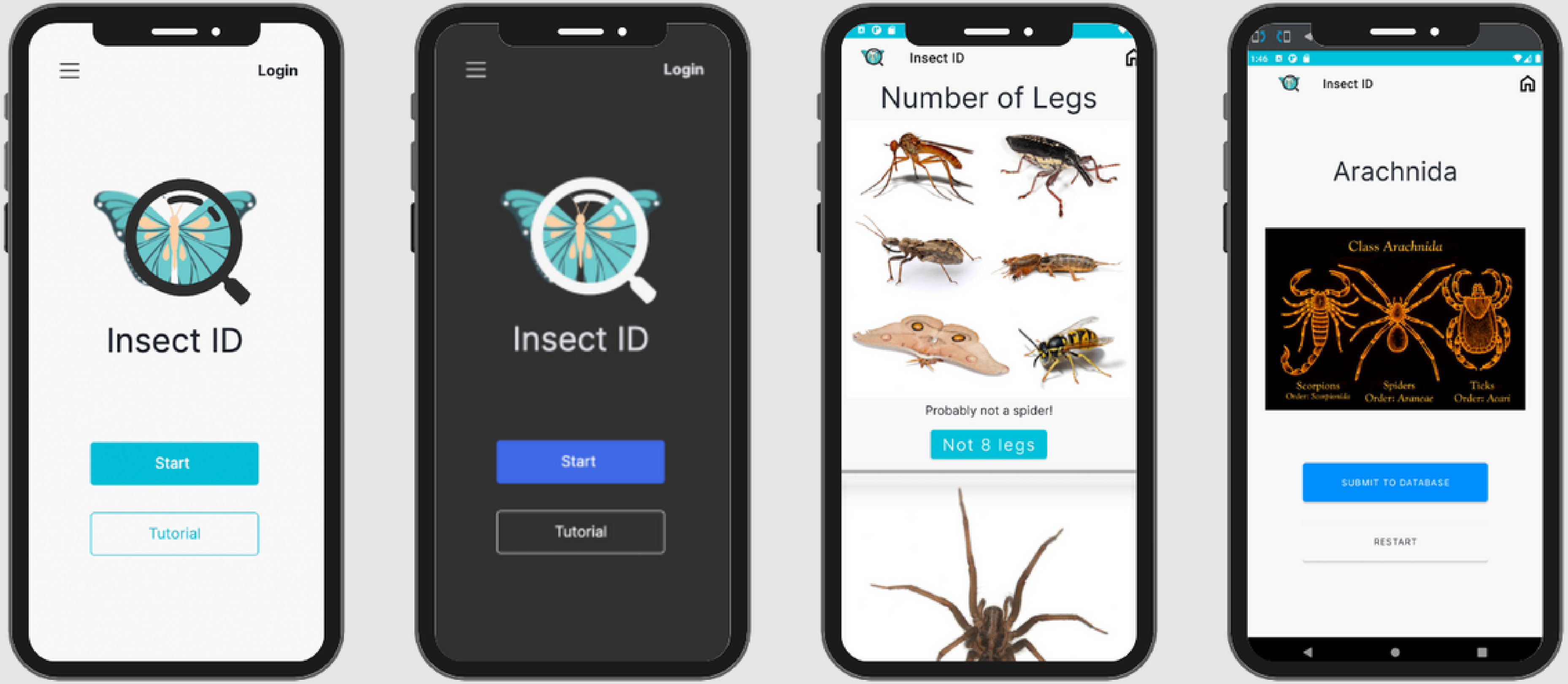
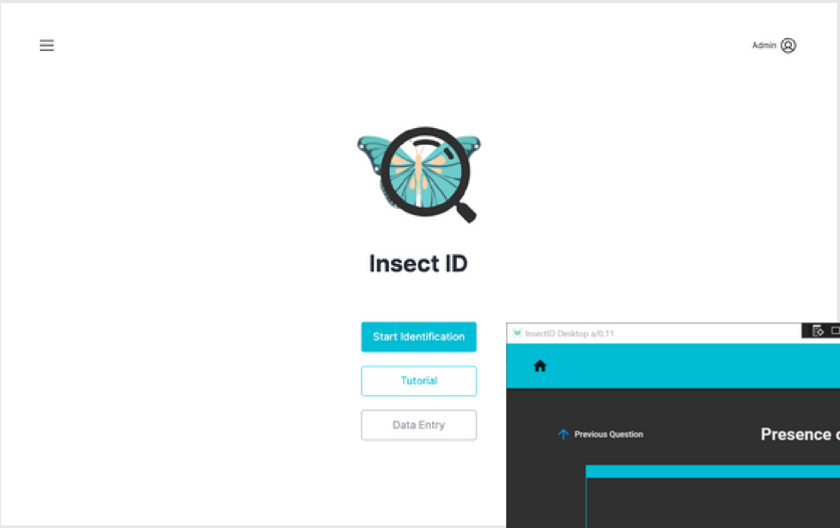
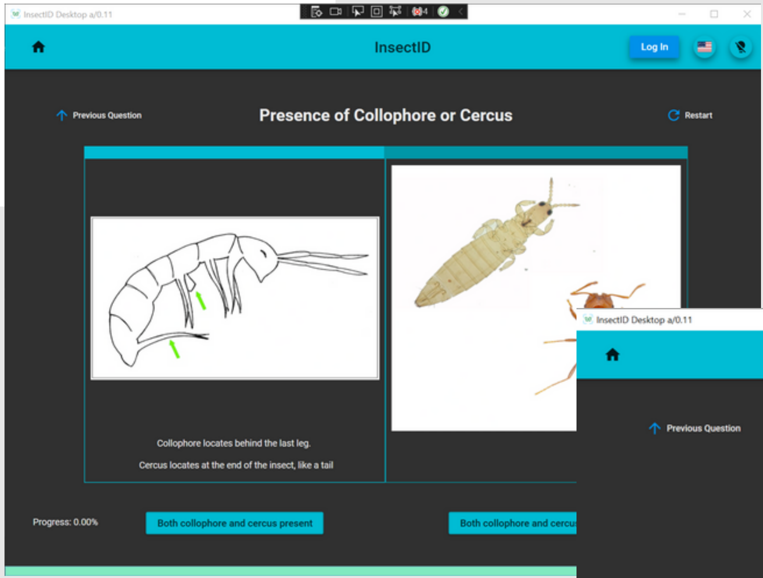


Figure 18: Mobile application for insect identification.





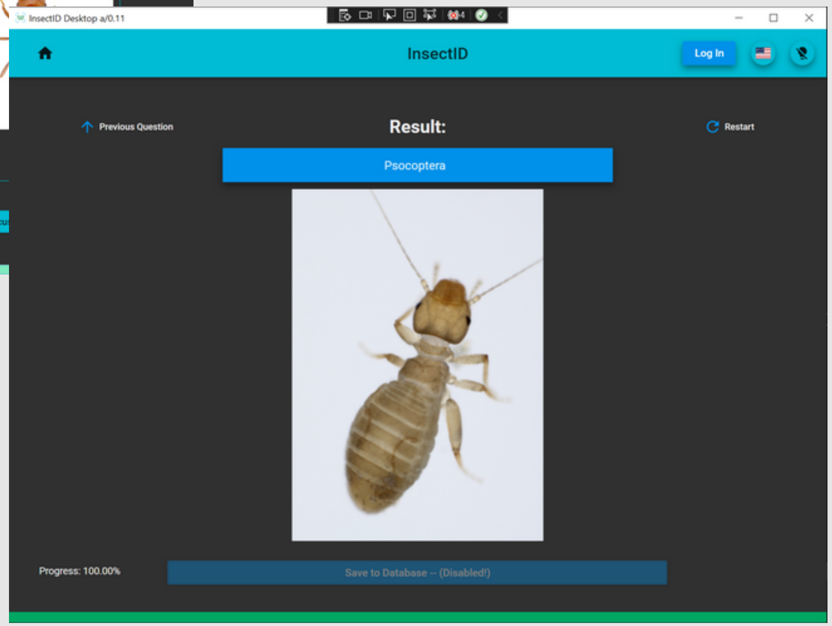


Figure 19: Desktop application for insect identification.

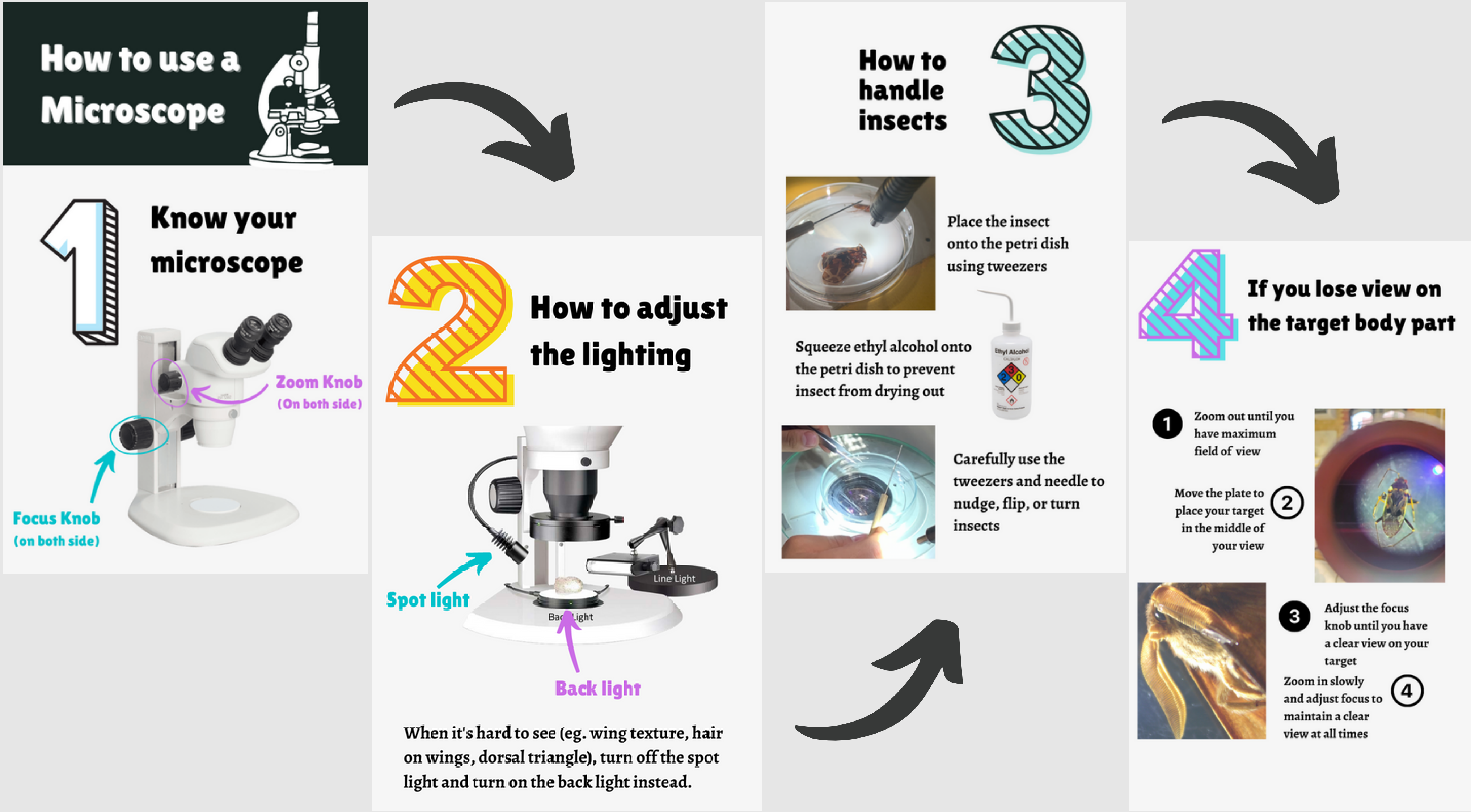


Figure 20: Microscope instruction for citizen scientists..

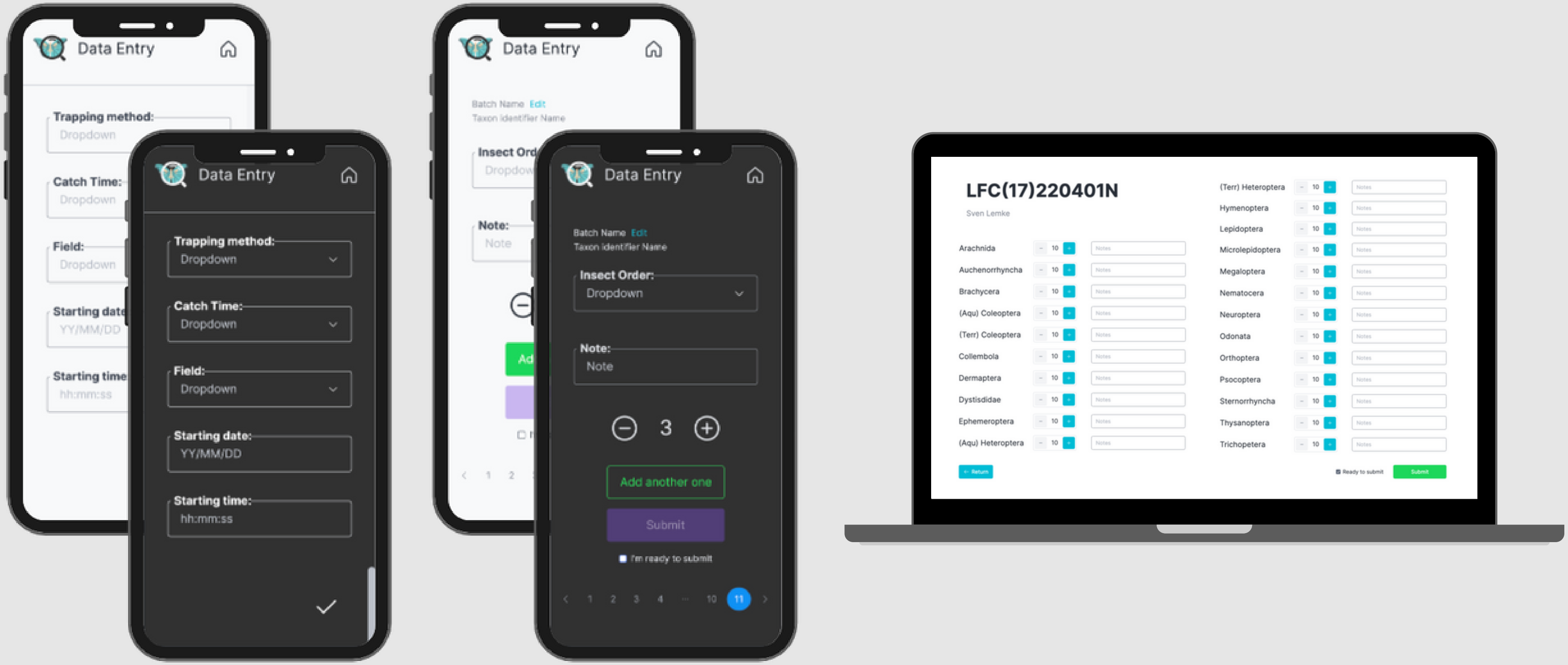


Figure 21: Mobile and desktop application for data entry.

Conclusion

The rapid decline of the global insect population demonstrates the need for scientists to conduct further research on the long term impact of Artificial Light at Night on insects. To do so, the scientists must first collect more data on both the number and order of insects impacted by ALAN. In our project, we developed an insect identification key that classifies 24 orders of insects and implemented it into an application to be used by citizen scientists. Furthermore, we also integrated a data entry feature in our application that allows the professional entomologists we worked with to record their data more efficiently.

The AuBe project at the IGB, through its five locations, currently identifies up to 10,000 insects each year by hand. Our digitized dichotomous key will accelerate this process by minimizing the time required per identification. In addition, since the interactive application reduces the need for professional guidance, it allows more citizen scientists to be invited per session to identify the insects. Lastly, the digitized data entry feature mitigates the need for professional scientists to verify the entries that the citizen scientists recorded.

The AuBe project, started in 2019 and runs until 2025, plans to use our application for insect identification and classification, which will enable more insects to be identified in less time. The data collected through the application will contribute to AuBe's research into Artificial Light at Night and its adverse impacts on biodiversity, which serves to provide evidence for the necessity of insect-friendly streetlights. In fact, one of AuBe's main projects is focused on the negative impacts of the current German streetlights and the development of new streetlights [37], a prototype of which can be seen in Figure 23. In order to produce a comparative study for the streetlights, it is essential to collect data on the number and type of insects attracted to both lights, which we hope to provide via our application.

We are honored to have the opportunity to apply our knowledge in computer science and design in making an application that can contribute to meaningful research with impact. In the course of this project, our team learned an enormous amount about insect biology, taxonomy, and preservation. We hope that our project will assist IGB's scientific research in insect preservation.

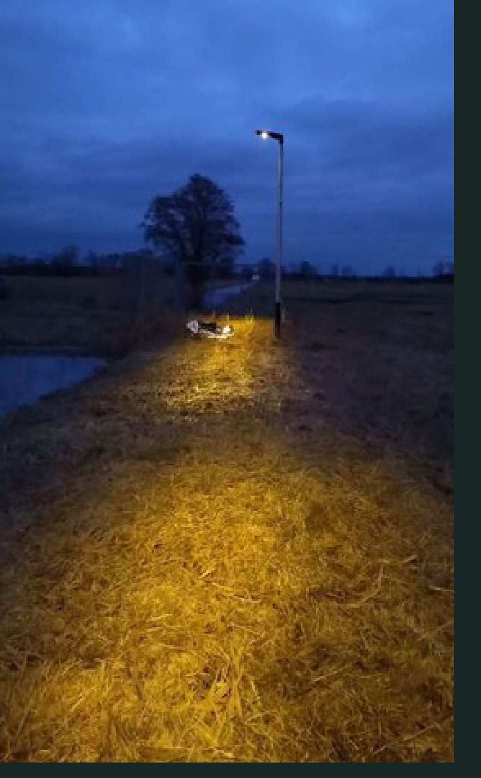


Figure 23: A prototype of Aube's insect-friendly streetlight [38].

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