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The INSpECTor: Removing Barriers to Efficient Specimen Analysis by Reduced Specimen Repositioning

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The INSpECTor: Removing Barriers to Efficient Specimen Analysis by Reduced Specimen Repositioning

By

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for the Degree of
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The Inspector: Removing Barriers to Efficient Specimen Analysis by Reduced Specimen Repositioning

Abstract

Entomology is the scientific field dedicated to the research and study of insects. In the last several decades, many journals and scientific papers have addressed the decline in insect populations worldwide and the increased need to understand the reasons for this. Many have called this decline an indicator that we have entered a “Sixth Extinction” which would lead to a mass extinction of life on Earth. How can we as designers provide assistance to the scientific community who are working to understand and provide solutions to this natural crisis?

As an Entomologist's primary tool for observation, microscopes and other optical technologies have developed to provide sophisticated solutions for imaging both singular and multiple insects.

However, the process of positioning them for imaging has largely been ignored by companies that design and manufacture imaging equipment. Accurately positioning an insect for study or preparing for digital preservation can be a time consuming and repetitive task even for those with extensive practice. This can lead scientists into choosing simple tools that are quick to use but often are hand held or rigid tools that can't be easily adjusted if the view and position of the insect needs to be changed.

Repositioning the original view inevitably costs time/money and increases handling of a fragile specimen. Additional difficulties arise when attempting to study their underside or physical features that extend beyond the length of the standard needle that they are mounted on; and then compound this with inadequate equipment solutions. I am proposing a new device called the "INSpECTor", a 2 axis positioning tool that is manually controlled by a belt system that mimics the hand's natural movements and more importantly allows for adjusting the position of a pinned insect in real time while remaining stable, creating a safe zone around a specimen, and improving lighting.

Keywords - Specimen Manipulator, Dome Lighting, Universal Stage, Specimen Holder, Rotary Axis, Taxonomy

Introduction

Collectively, the current state of entomology research is indicating that over the next couple decades we could see a 40% extinction of the world's insect species. One very significant study to document insect population decline was published in 2017 (Sánchez-Bayo, 2019). It was based in Germany and showed a 76% population decline over a 27 year span. Many people saw this study as a final call to the global community that our ecosystem is in distress and we need to act fast in order to resolve it. Several other groups have recorded similar declines to strengthen this concern and need for heightened awareness.

Entomology represents a small portion of biologists internationally but scientifically forms the foundations for all ecosystems. Because of this small professional market share, few products are aimed specifically toward entomology. Unfortunately over the pandemic, Bioquip, a US based entomology company and arguably one of the best international sources for equipment and resources, had to close its doors after international travel and expeditions were not taking place and supporting their business. This only strengthens the relevance of supporting this group of vital scientists to our global health.

With an international decline in biomass (Lehmann 2020, Mikanowski 2021, Sánchez-Bayo 2017, Tseng 2018), and a small market segment that only provides the necessities for insect imaging, how can we as Industrial Designers assist scientific efforts to preserve and restore Insect populations through good design?

In recent years digital preservation of species has become an increasingly popular trend within entomology and museum curation. As specimen collections age and access to them becomes more exclusive, digitization enables both the public and individuals outside of a serviceable region to view and use the rich biodiversity that would otherwise be unavailable. Insects, while arguably easier to photograph due to their small size, become a much more daunting task when considering their exoskeletons vary in texture, reflectivity, complex geometry, and complexity of high magnification imaging. In evaluating the processes related to specimen inspection, there are two large areas of opportunity that present themselves.

First, positioning devices that are commercially available are not intended to be used as an active movement device but rather are intended to be prepositioned. If adjustments need to be made, doing so while still looking through the microscope is challenging and not recommended (Dupont 2015, Boyadzhiev 2006/2012, Plum 2021). So creating a device that provides specimen positioning and the ability to change that position during use would be a substantial upgrade to the industry. This would enable quick rotation and inspection of an insect and permit the user to leave the specimen in position while addressing another task with their hands(drawing, cleaning, note taking, etc).This could also double as a stable base to use in conjunction with vertical focus stacking photography setups.

Second, some institutions can afford or receive grants to use advanced 3d imaging and scanning equipment that are starting to emerge for insects (Open Science 2023, Plum 2021, Nguyen 2014). However, most institutions that host entomologists have high quality stereo microscopes that often last at least 10-30 years and are detachable from their bases and have trinocular/simufocul ports (a viewing port for cameras or other accessories). Designing a motion system base that provides a digital interface to control the microscopes X, Y, and Z axis while incorporating the positioning system mentioned above. Effectively converting these high quality microscopes into more usable focus stacking machines with advanced positioning capabilities for research publications and digital preservation databases. 3d scanning would also be a function of this automated motion system via photogrammetry.

<u>The focus of this paper will be to investigate the first option, a manually operated positioning device with active adjustment capability.</u>

Problem Statement:

If we have entered “The sixth extinction” (a massive drop in the collective biodiversity of the earth with potential to cause a mass extinction of life) how do we equip scientists with the right tools to understand its impact on targeted species? Insect health forms the base for all ecosystems; what specifically enables entomologists to evaluate species health, development and decline?

Research & Considerations

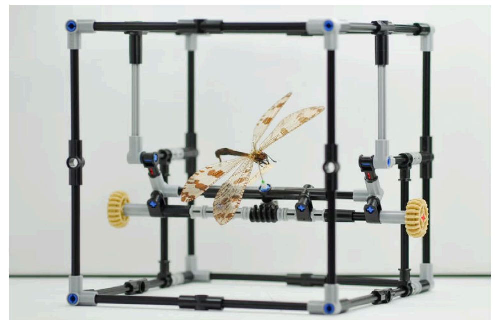


Figure 1: The Lego Insect Manipulator (Lego Imp) that was created by Steen Dupont to provide safe specimen handling and enhanced positioning.

One of the initial inspirations for designing an insect manipulator was based on seeing a design that was created with Lego Technic parts in fig.1 (Dupont, 2015). Insect specimens are extremely fragile. Once they are mounted to a needle, they will dry out and their exoskeleton remains in its original shape but the joints become brittle. It is common for legs, antennae, wings or other parts to fall off, leaving older samples with few of their original limbs attached. While research exists that evaluates methods for imaging and the specific ways that institutions have built their own manipulators, the market has not translated that data into effective product solutions. Preventing drops, physical contact, cleaning accidents, etc, while also enhancing the observational experience seem to be very separate despite their important role of preserving a specimen’s integrity.

Figure 2: Currently available specimen manipulators on the market. Left: Entoball, Bioquip Microscope Stage(unavailable), Dino-lite MS16K, Watkins&Doncaster Insect Examination Stage, Dino-lite MS16C

Figure 3: Publicly shared creations from both entomology and macrophotography communities as they have all tried to solve the dilemma of effective specimen positioning.

The dismal market offerings (fig. 2) revealed that most manipulators are lacking important features to facilitate their intended use and many do not survive as viable businesses (Bioquip as well offered products from a “Rose Entomology” that offered high quality products that the community misses). It also became apparent that community members were creating their own devices to fill the void that the market was not fulfilling. Similarly, most journals or scientific articles related to this topic often suggested that they were not creating additional copies but rather only wanted to share their exploration/solution. This almost creates the impression that an important achievement to operating in the industry is being able to create your own solution for studying or photographing insects. Many common challenges that I have identified with manipulators were solved with the Lego Imp; specimen safety, range of motion, reasonable cost, and global accessibility. These 4 categories form what I will consider to be the minimum requirements for good design as it relates to insect manipulators. Additional categories that would further enhance a future design would be lighting and user ergonomics. How would each category define success or failure? Do these criteria provide enough space for a device to meet their collectively high expectations?

Specimen Safety: Is there a clearly intentioned feature that protects a specimen from damage such as a cage or cover? Is the needle placement going to hold securely while the insect is being manipulated into the desired viewing position; potentially upside down? Safety appears to be a feature that only a scientist possesses, not their instruments.

Cost: Scientific equipment typically demands a premium price for its strict demand for performance. Would an individual without grant funding or special financial resources be able to purchase this for their own use? Most microscope accessories that are from a respected brand usually exceed $200USD as a starting point. Most insect manipulators are between $20-$90. Can a viable solution be created for less then $75?

Global Accessibility: Most companies ship parts and products internationally. Is a complete product or instructions for a kit more accessible? Will they have access to the required tools, components, and other necessities? Is 3d printing a technology that is available internationally? Can we assume that organizations that focus on research or employ entomologists have access to these machines, or online manufacturing services, or local hobby enthusiasts that can be enlisted?

Range of Motion: Is it possible to provide 360 degrees of movement in at least 2 degrees of freedom? Most microscopes are considered 3 axis machines, is an additional 2 degrees of freedom enough to eliminate any blind spots for observation? Is it possible to control motion remotely to prevent accidental contact with a specimen? Many inspection devices are not designed for insects larger than 30mm in diameter, how large can we plan for to facilitate a universal tool for several species or several scientists to commonly use?

Lighting: A microscope would be near useless without an appropriate light source to illuminate the subject for viewing. Likewise, the type of light and how it interacts with an insect largely impact the quality of the image. Beyond routine use, manipulators rarely take into account their effect on the background of an image or obstructions that require extensive image preparation prior to use in publications or other presentation cases. These post processing efforts cost time/money that could potentially be avoided. What if the manipulator made photography better rather than worse? Could lighting principles from integrating spheres, the square law, and photography lighting form a foundation for successful integration?

UX/Ergonomics: Stereo Microscopes are table top machines that typically operate with a series of knobs that adjust the focus and height of the microscope in relation to the specimen being observed. These knobs are usually near the top of the machine which requires the user to lift their arms and sustain a lifted position through the duration of adjusting the view. Reducing time spent adjusting the focus reduces user fatigue and increases user efficiency. What is the most natural position for a user to maintain while using a manipulator?

Design/Prototyping/Testing

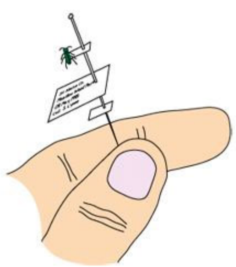


Figure 4: Illustration of holding a pinned insect between the thumb and index finger. The wrist can tilt toward or away from you and you can twirl the insect left to right.

A simple observation of how someone naturally rotates a pinned insect with their fingers revealed that the most natural rotational movement would be on the A-axis (rotation around X-axis) and C-Axis (Rotation around Z-axis). Turning toward the design of common microscopes, most use knobs to control both the movement of the stage that a slide or specimen is placed on and knobs to control the course and fine focus. It seems a natural choice to continue using the intuitive design of knobs as the user will already be familiar with them. Additionally, knobs provide a rotation based input to a machine that will translate well to the rotation of a device.

Inspiration Image Grid

Figure 5: In trying to understand the ways that others have created movement across several axis, I turned to these examples as inspirations for thought. Left: dentistry drill from the early 90s, modern camera gimbal, a 3d printed 3d scanner, the ScAnt - a 3d scanning device for creating 3d models of insects.

Ideation Sketches and Size Mockups

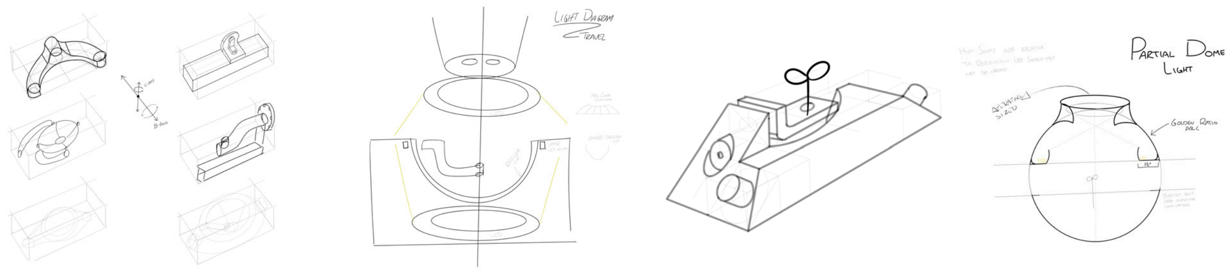


Figure 6: Initial digital sketches that focused on physical forms, lighting, and potential user interfaces.

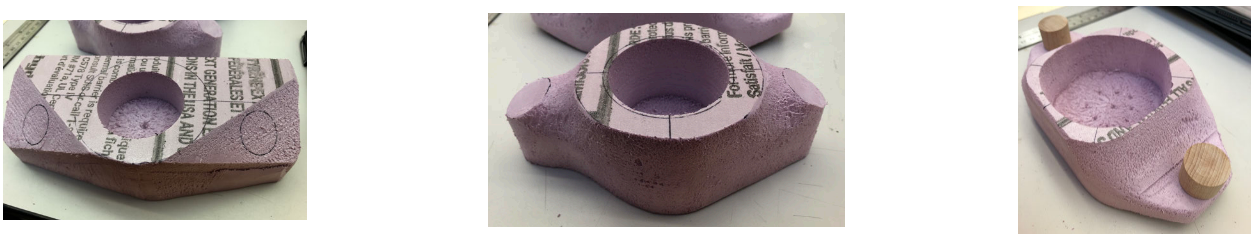


Figure 7: Foam mockups for size and function testing with a microscope

Very quickly it became apparent that lighting was an essential consideration for this design to be successful. Because most insects have an area on their exoskeleton that is reflective, a very diffuse light needs to be used to remove the sharp highlights and shadows that direct light produces. Other entomologists that have made efforts to improve lighting by designing dome light diffusers (Balmier 2020, Kawada 2016), altering the shadow profile of a diffuser for more desirable reflection artifacts (Kerr, 2008) and stacking various filters to diffuse light sources.

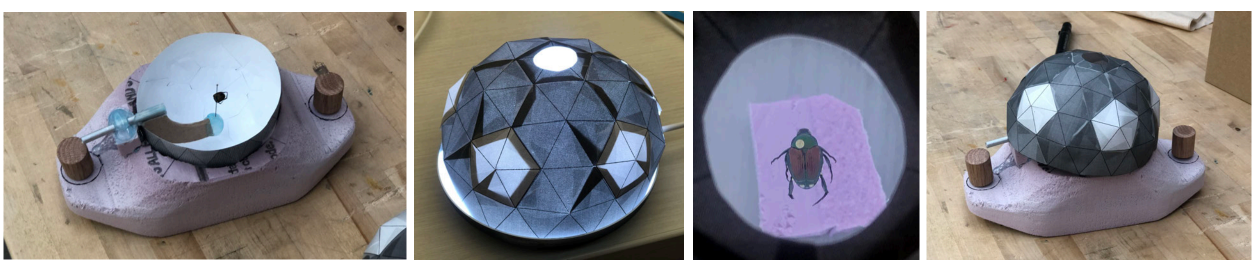


Figure 8: The foam mockups were also used to test simple light domes to gain experience and understanding of the lighting challenges that needed to be solved.

Early CAD Models

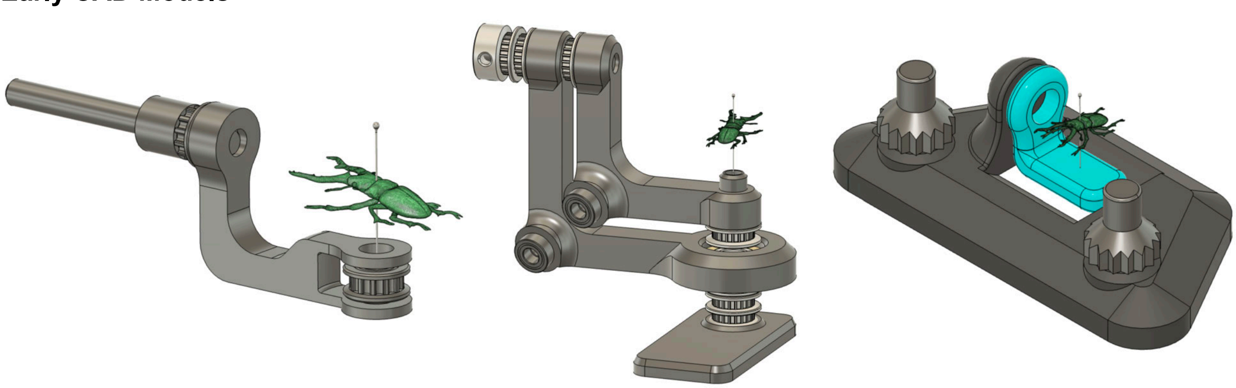


Figure 9: The earliest models focused on the belt system that would be needed to create the desired motion for the specimen. Some form consideration was attempted but ultimately very difficult without the mechanical design completed.

Early Lighting Concepts Exploration

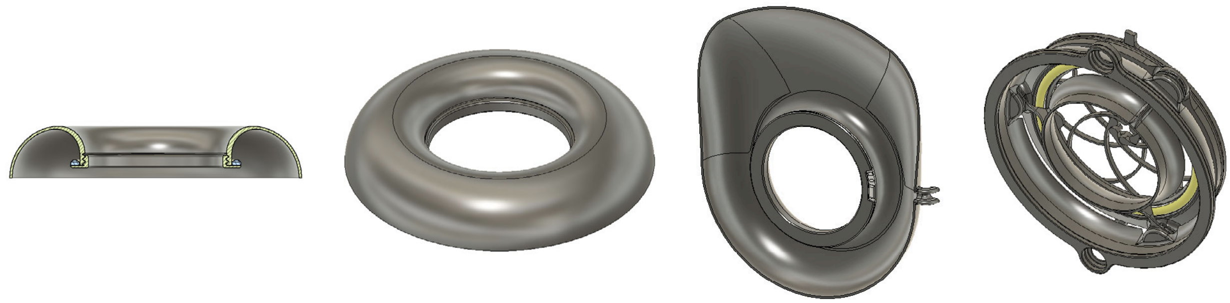


Figure 10: Early designs for the lighting incorporated large curved surfaces to redirect the upward facing LED's light back toward the specimen. This technique of bouncing light creates a more diffuse light that prevents or eliminates hot spots and reflections that negatively impact scientific images.

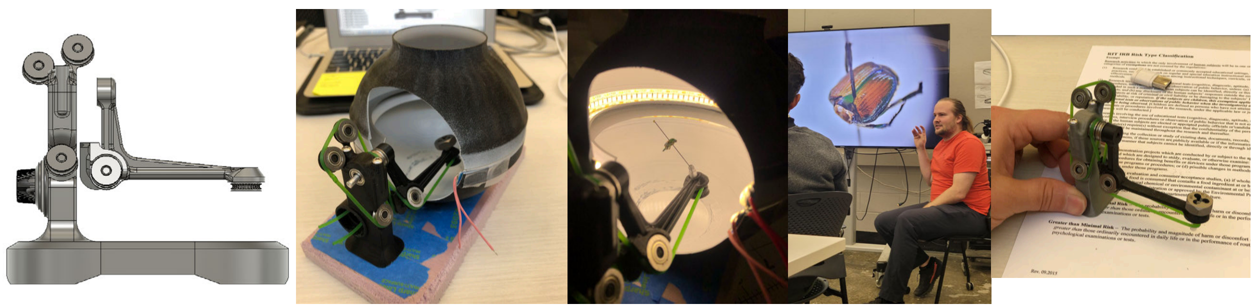


Figure 11: This was the first complete testing of the lighting, positioning arm, and camera mount in order to project an image to a presentation screen or capture still images.

The initial dome was painted but proved to be too reflective and created sharp highlights and hot spots. A further revision of the profile and surface finish will need to be taken into consideration.

Supplemental Proof of Concept Prototypes

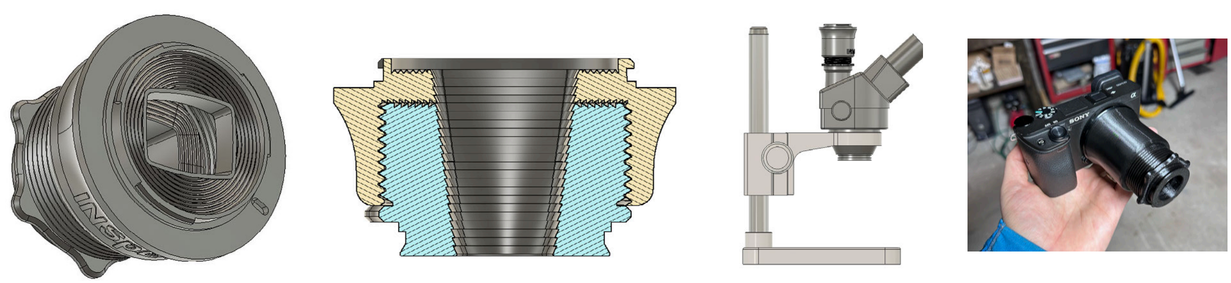


Figure 12: In creating solutions that do not yet exist, there were multiple objects that had to be made, a custom camera mount was one such needed object.

In order to continue developing the positioning system design further, I had to develop a functional camera adapter for a Sony A6400 and light that could produce diffuse light. An initial design was made to work in tandem with the positioning system, however the lighting system proved to not be powerful enough for higher magnification imaging without further refinement.

Figure 13: These lighting prototypes used a variety of LED ring lights and the two center images show the most successful design that attaches to the microscope and provides the most diffuse light.

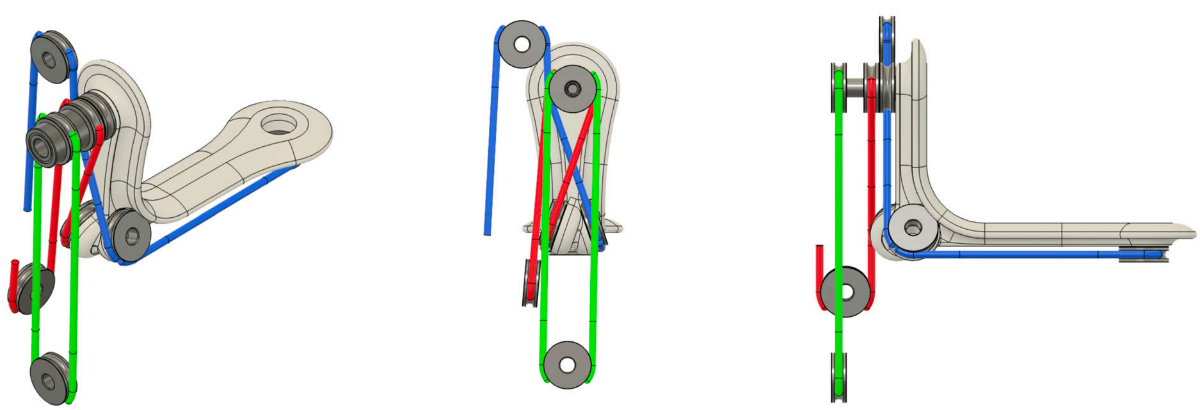
Integrating Systems Prototype

Figure 14: This prototype shows the first integration of integrating sphere, positioned arm, and upper light.

The belt routing was finalized with prototype #5 that is pictured above. This involved wrapping the belt in such a way that the tension of the belts counteract each other in order to rotate smoothly around the horizontal A-axis and also determine the maximum angle of rotation based on the idler positions. This version used polyurethane belts that had to be pretensioned in order to have enough friction to operate. The high tension later one proved to be a problem as it was warping the 3d printed components.

Belt Movement System

The mechanism behind the motion system of the inspector is made of 2 belts. The A-axis (green) creates a swinging motion and the C-axis (Red/Blue) creates a spinning motion. These belts are mostly



hidden inside of the device for aesthetics and safety. The arm will swing to its bottom position at 0 degrees of rotation when you are placing a specimen onto it and then the typical starting point for inspection is at 90 degrees or horizontal position because the bug will have rotated to face the viewer.

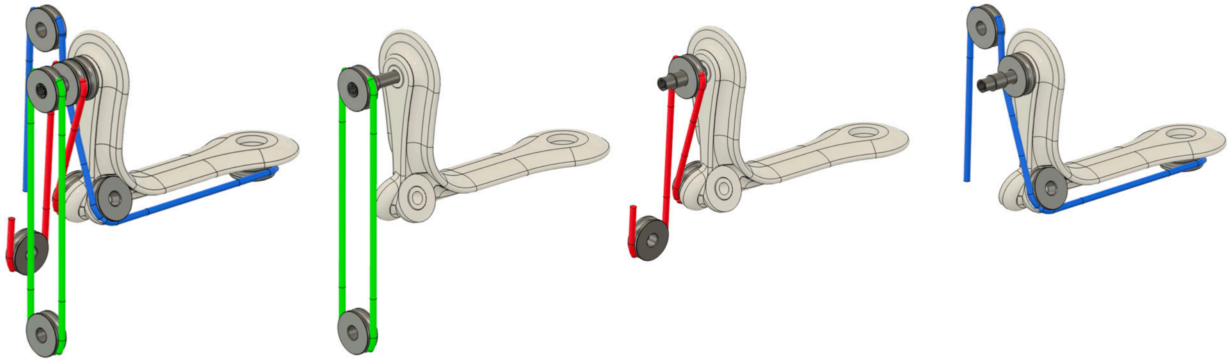
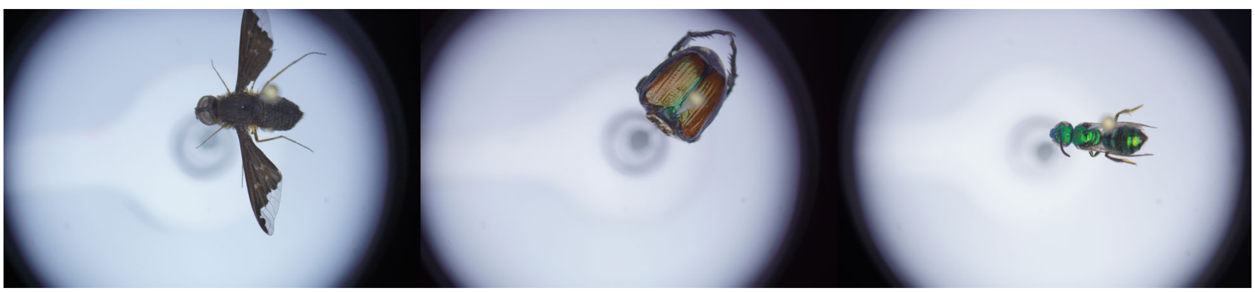


Figure 16: The A-axis(Green) will swing the insect up or down. This changes the view from seeing either the top of the insect or the bottom.The C-Axis(Red/Blue) will spin the insect in a horizontal circle. This changes the view from seeing either the left or the right of the insect. Since this belt has a twist and overlap, it was easier to understand by using two colors to represent the applied rotation. Red is counter-clockwise and blue is clockwise tension.

Picture Testing



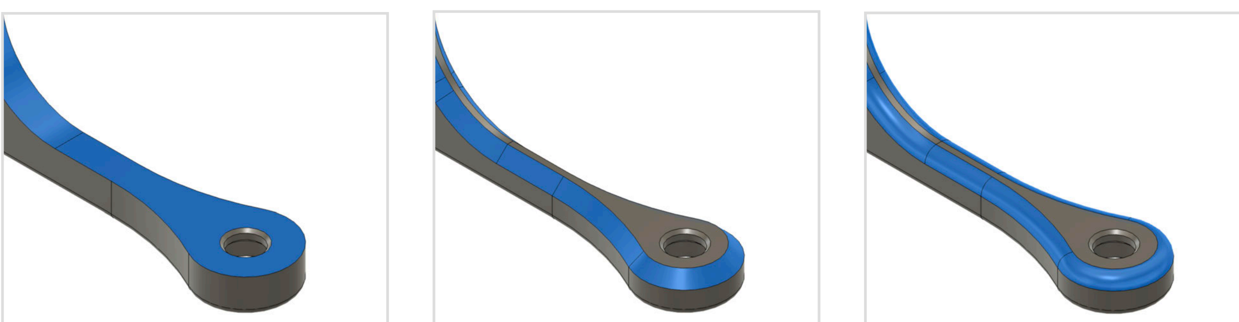


Figure 17: Initial testing of the arm's profile showed a noticeable impact to picture quality based on the edge profile. The further right test being the most successful.

Picture background testing revealed that the sharp edges of the flat top and chamfer edge arm created a more noticeable discoloration on the background than the round/filleted edge. Taking it a step further, I expanded the edges of the arm as shown in Fig. 18 so that only one edge was visible at a time from an overhead view. This greatly minimized the visual impact.

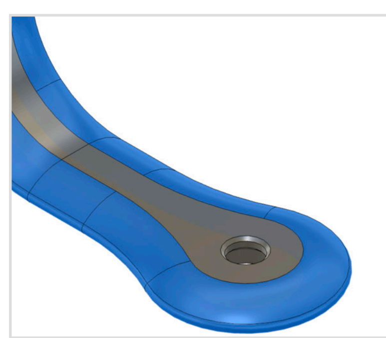
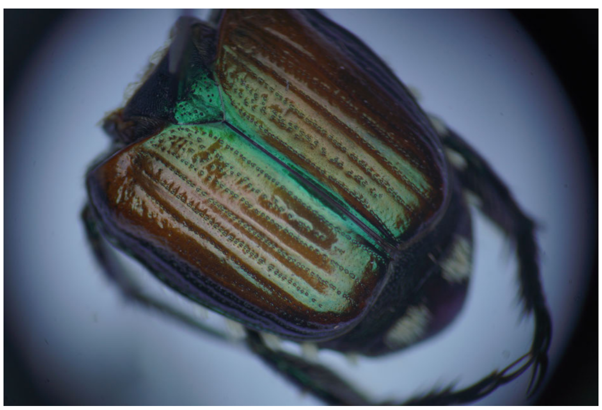
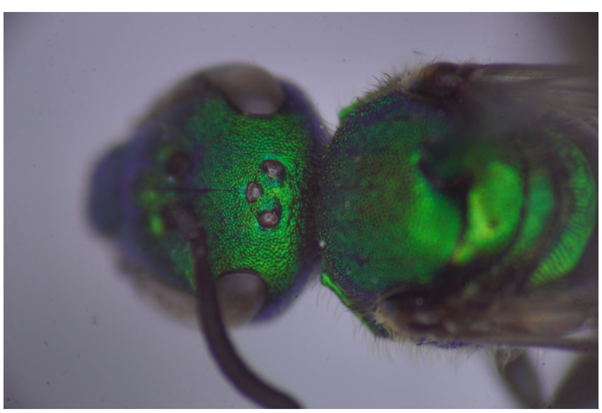


Figure 18: The final edge profile uses a large radius to minimize shadows and final image editing.

The picture test also used an exposed metal center with hot glue to hold the needle in place which left a very noticeable dark circle. This has been exchanged with a matching white center piece that utilizes nylon bristles as mentioned by (Dupont, 2015) for a suitable and reusable needle placement.

Picture Testing with the Diffuse Lighting and Integrating Sphere Lower Dome





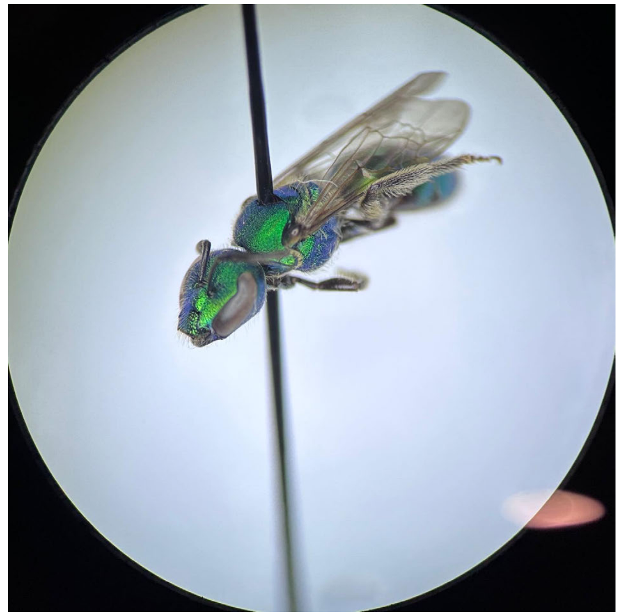


Figure 19: These tests showed the best results to date, however, there are still aspects of diffusion and lighting that need to be addressed.

User Testing

Testing was done in 3 rounds; **(1)** This round was comprised of (12)10 year olds to determine if the concept was intuitive with individuals who have no exposure to microscopes or insects. **(2)** This round was comprised of (11) graduate students who had little to no exposure to microscopes or insects. **(3)** This round was conducted with (7) industry experts that would be the primary user for this product.

Figure 20: 10 year olds that tested the design enjoyed being up close with insects without the fear of physical contact or harm.


Figure 21: Graduate students gaining experience with the prototype and comparing it to freehand manipulation.

Round 1 of Testing (2/15/23): Produced interesting results because there was no reference for the users to rely on. The microscope had to be operated for them to maintain focus of the viewfinder however they quickly learned to enjoy changing the position of the insect to see teeth and other “scary” features. Most were not comfortable enough to place their own insect into the prototype but they were all comfortable and excited to use the device with the microscope. This confirmed that with a little practice, a beginner could learn to use the device easily, and it enhanced their experience. One individual tried to hold a specimen by hand and realized how shaky their hands were and quickly opted to use the device instead.

Round 2 of Testing (2/22/23): Produced interesting results because I provided no support to operate the microscope or the device. The only negative feedback received from these tests was that using the microscope tended to be difficult; both focusing the image and aligning their eyes with the lens. Feedback that was received tended to state that they weren’t sure which knob controlled which direction of motion. All users approved of the wider hand placement that allowed them to rest their hands on the table while also using the device.

Round 3 of Testing (4/28/23): Took place at the Natural History Museum (London, UK) with Steen DuPont and several of his colleagues. They were able to test the "final design" version of the Inspector and provide very specific feedback. All individuals that interacted with it were able to say that it would be useful for them at some point in the completion of their assignments. Depending on the department that they were in, they did have feedback on how they would adapt its design to better suit their work(barcode labeling, different knob location, different mount designs). For the intended group that this was designed for, Taxonomist's, interest was expressed for a permanent copy to remain at the Museum. Some quotes from the visit include: "Best of its kind that I have used", "Very intuitive", "Makes me want to look at bugs for fun again".

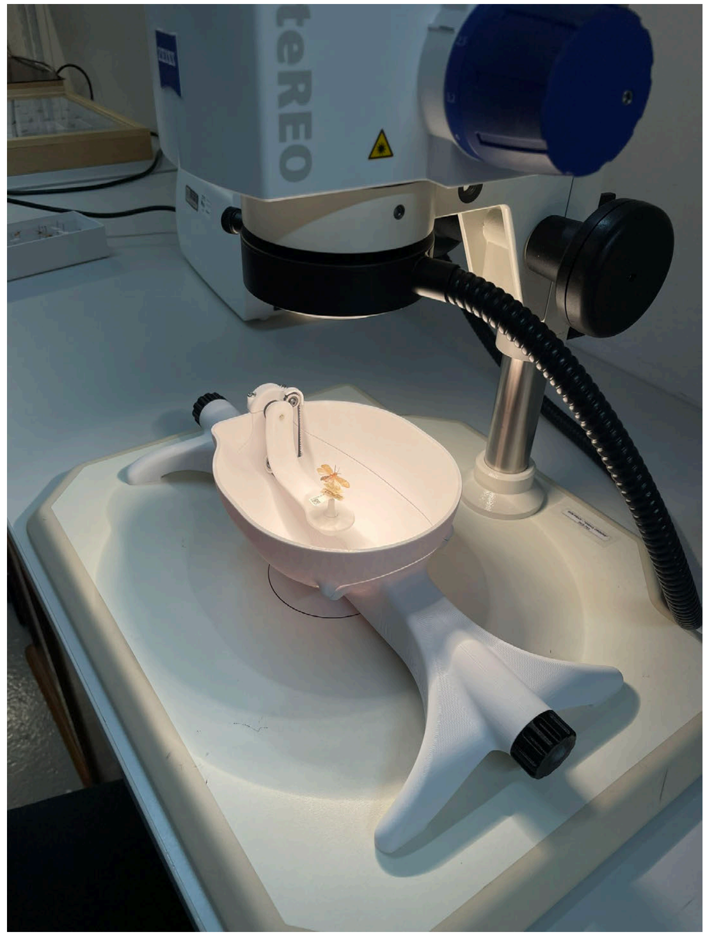


Figure 22: The Final Design being used with a NHM staff microscope.

Summarized Feedback from Round 3

- Can it be cleaned, repaired, and handle intense use? Inspect 500 - 1,000 specimen daily?
- A place for barcodes would be essential for use as a digitization tool.
- A mount that holds the head of a pin for completely upside down viewing.
- A mount to accommodate off center or card mounted insects.
- Including a few darker fibers into the needle mount would make it easier to insert a needle.
- More friction or a locking button to prevent the arm from settling slightly after your let go of the knobs.
- The strong magnets used could produce a jolt to a more fragile specimen.
- A Z-height adjustment would eliminate the need to touch the microscope, that would be fantastic.
- For photography, a complete lighting dome that still provides access to the insect would be great.

Form Refinement

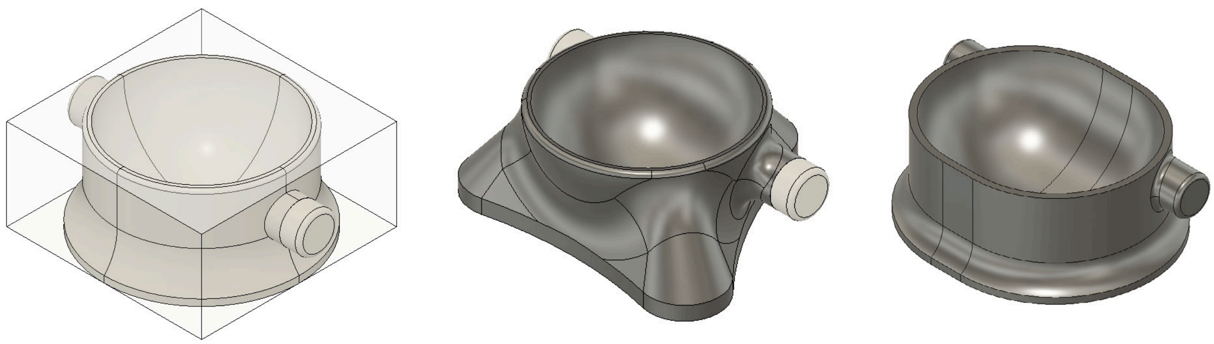


Figure 23: Simplified forms that were made to investigate a more compact design.

Through testing rounds 1&2, the proof of concepts were able to confirm the design and functions. I wanted to create a softer form that was approachable and fit some of the aesthetic of current scientific equipment. I wanted to reduce the form to its most simple shapes which resulted in the forms above. While this was a successful exploration, ultimately a revision of a previous design was chosen.

Figure 24: Final Design from that was a revised and modified design from prototype #5

The final design is both a very organic form but also has a very structured feel. It maintains a wide base with knobs at the sides that control the movement of the specimen and the dome is partially removable to facilitate better access when installing or removing a specimen. This dome also creates a safe zone in addition to enhanced light.

Final Design

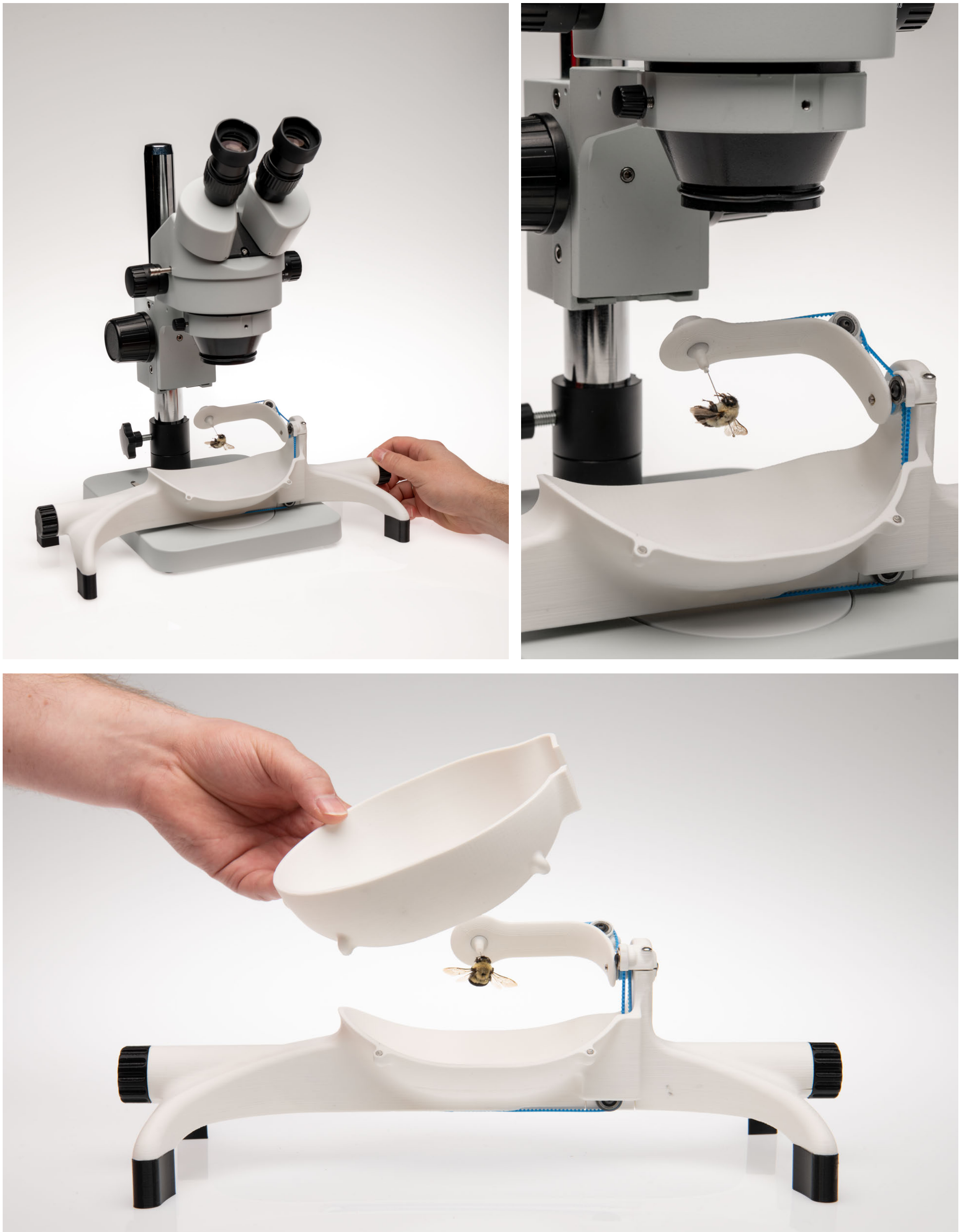


Figure 25: Product photos highlighting the object scale and the removable lighting dome.

Final Design

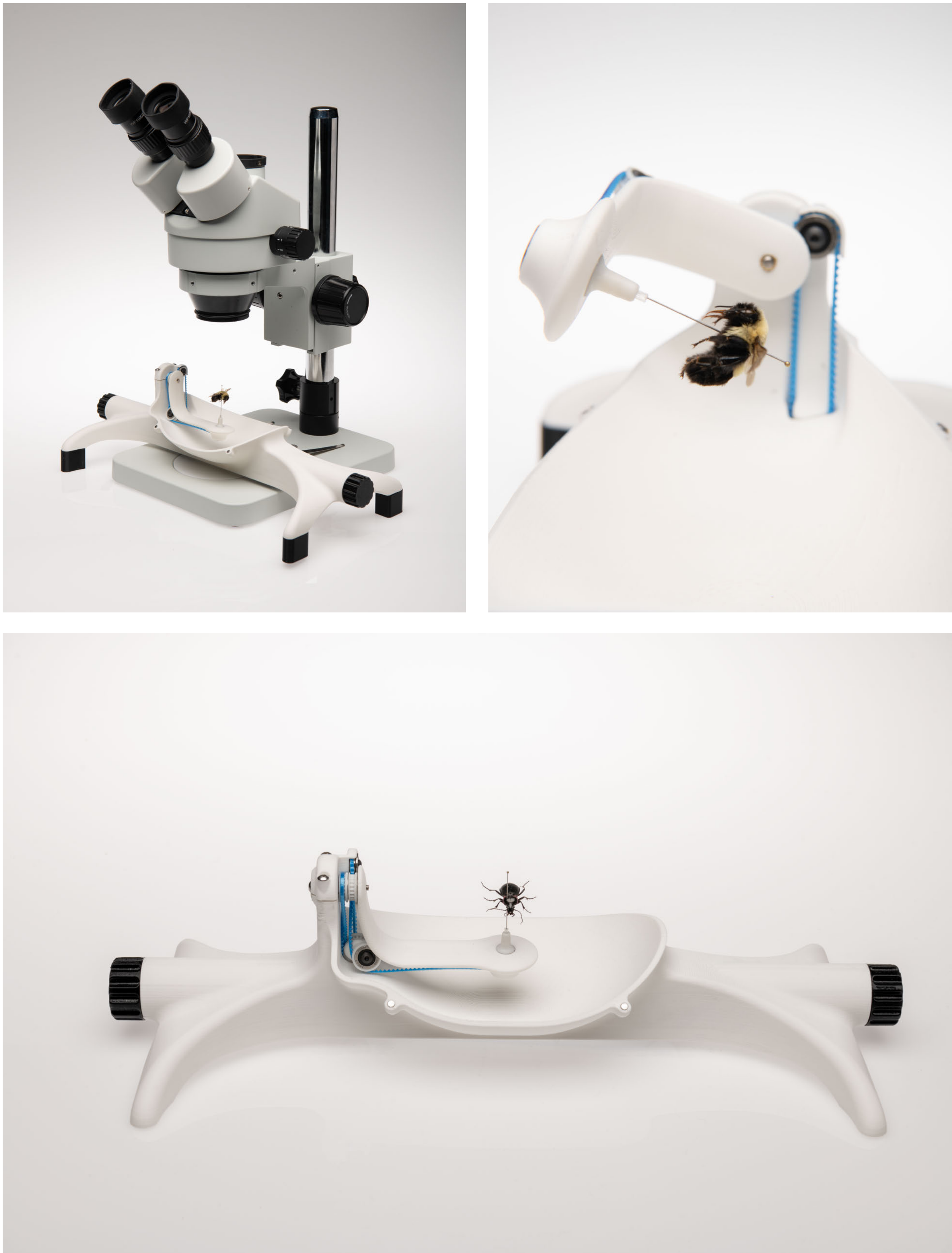


Figure 26: Product photos highlighting the rotating arm and access to the specimen with the lighting dome removed.

Conclusion

Through an extensive design process that ultimately resulted in 7 distinct prototypes and 3 rounds of user testing, it can be concluded that this device is not only successful as a mechanical device in isolation but also performs to the expectations of the industry professionals that it was designed for. Scientist were quoted to have said “this makes looking at bugs fun again” and “This is the best design on the market”. As previously outlined in the research of this device, in order to be considered a good design it needed to meet the requirements of specimen safety, range of motion, cost, global accessibility and a bonus for lighting and ux/user ergonomics. I would contend that this design has successfully met each of those 6 areas of requirement. Specimen safety and lighting were accomplished together as the lighting dome both enhances specimen lighting and creates a safe area that prevents contact without limiting visibility. Range of motion was accomplished by achieving 180 degrees of motion in the A-Axis and unlimited 360 degrees of motion on the C Axis; Combined they provide full access to the entire specimen. Cost and global accessibility are also joint accomplishments with the advent of 3d printing. In total, the materials cost was $35USD (not including energy or machines) to produce and all components are considered standard off the shelf components that anyone or country would be able to source. Finally, ux/ergonomics are potentially the largest contributors to this design as the hand positions, knobs, removable light dome and several other user interactions were taken into consideration for work flow and functional use.

After having completed this project, additional uses have already been found! Within accessibility, I was approached by a student that is legally blind who typically needs an enlarger screen to see the output of their microscope and the INSpECTor is a perfect solution that can hold a specimen in place and safely manipulate its position which tend to be their largest limitations when using a larger visual aid setup. Another adaptation has been the inclusion of a mount capable of holding fibers which tend to be difficult for positioning and observation.

When considering the areas for further refinement and development, the main concern that remains is lighting. In its current state, the mechanical movement was prioritized over developing a diffuse lighting source. This decision was made because often times the lighting is only emphasized when creating images for publications rather than everyday use and most microscopes already have powerful lights on them where diffusion is less of a concern. The dome that is currently incorporated in the design serves as a light reflective surface that removes shadows from the bottom and sides of the insect and will reflect the same light quality as it comes from the source. Adapting a complete upper dome that generates a diffuse light would be a beneficial next step for those pursuing publication level lighting.

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