Department of
Biomedical Engineering
UNIVERSITY OF WISCONSIN–MADISON

Dual Handheld and Video Otoscope

Final Report

BME 200/300
12/13/2023

Client:

Dr. Lara Tomich- University of Wisconsin Veterinary School

Amy Nichelason-University of Wisconsin Veterinary School

Advisors:

Justin Williams- Professor of Biomedical Engineering Adjunct faculty of Neurological Surgery

Team Members:

Sam Tan- BSAC/TeamLeader

Grace Boswell- Communicator

Haoming (Bobby) Fang- TeamLeader

Jose Ramirez- BWIG

Declan McHugh- BWIG

Zakki Miraz- BPAG

Abstract

Teaching otoscope techniques for animals poses a challenge, particularly for novices who rely on instructor guidance. Existing otoscopes can be broadly categorized into two types: handheld and video. While a video otoscope is powerful for examinations, it is practiced differently than a handheld otoscope, the primary tool used in animal exams for students at the UW Vet School and likely to be used by students at future practices. However, a challenge arises as handheld otoscopes do not provide live video or replay for instructor feedback during examinations. This feedback is essential for students' success and the animal subjects' well-being during practice. Therefore, there is a need for an otoscope design that can transfer live video to an instructor while providing students with an experience similar to using a handheld otoscope. The team's overarching goal is to design, fabricate, and test prototypes to address client requirements while maintaining a reasonable budget. Through design evaluations and fabrication, the team created an otoscope using a beam splitter and a camera to record the point of interest without interrupting students' viewing. Testing results showed that the otoscope prototype exceeded expectations, with subjects preferring the prototype to the conventional otoscope in comfort, weight, size, and overall usability. Areas for improvement were light brightness and monitor zoom and quality. The testing shows that the team created an innovative design that could serve instructional use here at the UW-Madison Veterinary School and others, and serve as a foundation for future innovations with similar goals.

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Introduction

Motivation/Global Impact

The use of an otoscope for examining the ear is a vital diagnostic method for identifying otitis externa. This condition affects the external ear canal, and it is an integral part of a thorough physical examination for canine patients. However, teaching such techniques still relies heavily on practicing with live dogs and is challenging for many veterinary students without proper instructions [1]. The development of a dual handheld otoscope, which seamlessly combines the technique of traditional optical otoscopy with live video capabilities, represents a significant leap forward in the field of veterinary medicinal education on a global scale. This innovative device promises to transform the way veterinarians are trained and educated by not only enabling real-time assessment and immediate feedback for improvement but also facilitating a comprehensive learning experience. With its integrated recording capability, this dual otoscope allows for a later review of the diagnostic process, enhancing the educational value of each examination. As a result, veterinary students and professionals around the world can access a more immersive and thorough training experience that better prepares them for the complexities of clinical practice, ultimately benefiting animal healthcare on a global scale [2].

Existing Devices & Current Methods

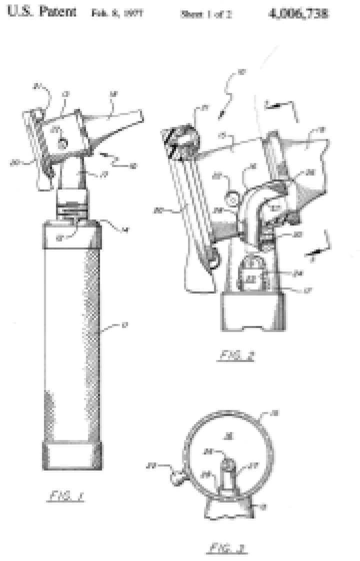

Figure 1: Structure of handheld otoscope [3]

Figure 2: Endo World Video Otoscope [4]

Current methods and existing devices for otoscopy training predominantly revolve around handheld otoscopes, as in Figure 1. These devices are the traditional otoscopes widely used in clinical practice. However, one significant limitation is their inability to provide instructors with real-time assessment and feedback capabilities. Trainees often struggle to replicate the precise techniques required for accurate ear examinations. Without immediate feedback, they may unintentionally develop suboptimal habits or fail to understand what they are looking at. In addition, inadequate usage of the otoscope also may be painful for the animals.

On the other hand, video otoscopes, as presented in Figure 2 [4], are another device used for otoscopy training. While they offer certain advantages, such as the ability to record examinations for later review [5], as well as slightly higher accuracy [6], they often function differently from the handheld otoscopes commonly used in clinics. This variation can create a disconnect between the training experience and real-world practice, potentially hindering students' ability to seamlessly transition to clinical settings.

Problem Statement

Current handheld otoscope designs in veterinary practice either cannot stream live videos of examinations to remote devices or feature video functionality instead of the traditional lens view, which is essential for simulation training. However, the veterinary faculty wishes to use traditional otoscope methods in teaching instead of focusing on practices with video otoscopes that are practiced differently. Thus the client proposed a device that features both handheld and video functions so the team aims to develop a handheld otoscope that is capable of live video relay to enable faculty members to assess student-performed examinations in real-time.

Background

Physiology and Biology Research

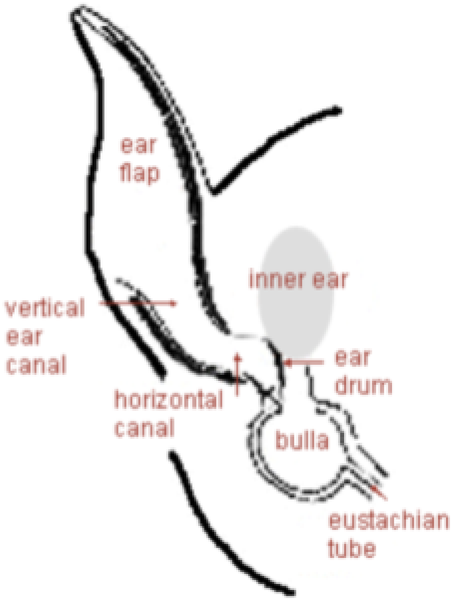

Figure 3: Diagram of dogs ear canal with labels [7]

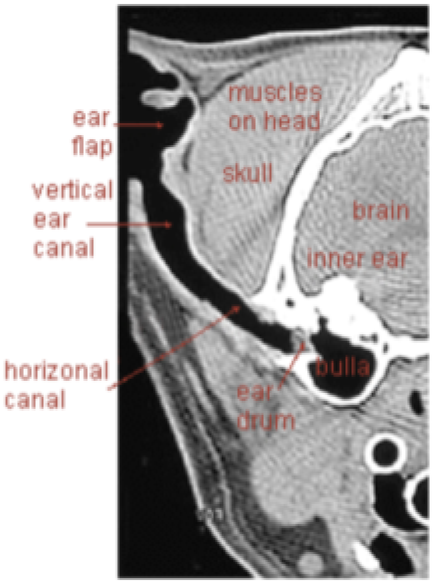

Figure 4: CT of dog's ear canal with labels [7]

The anatomy of a dog's ear consists of various structures shown in Figure 3 above. There are three main areas that veterinarians define as the outer, middle, and inner ear. Within the outer ear, it consists of an ear flap which is also known as the pinna. Next is the middle ear, which is known to be fragile. This is important to note in the team's design due to the device needing to be safe for the clients and the dogs they will be using it on. The middle ear also consists of three bones, an air-filled cavity (bulla), and a thin tube (eustachian tube). Finally, is the inner ear which connects to the brain, has nerves, and is involved in hearing and balance [7].

Design Research

A one-way mirror, or a transparent mirror, is an essential part of the design and a crucial element in achieving the success of implementing video relay capabilities into a traditional handheld otoscope. This idea was first developed before the semester began when group members were proposing this project. The use of a one-way mirror is to reflect only a portion of light hitting the surface. This allows the rest, typically a very small portion, to pass through the mirror thus viewable as a transparent glass from the other side of the mirror. A one-way mirror, unlike a normal mirror, has a thinner silvering on the surface. This thin coating allows the described feature to be achieved. The reflective molecules on this layer of coating make the mirror half opaque. However, there must be a brightness difference between the two sides of the mirror for this to be successful. The bright side is the reflected side thus lights are reflected so it acts as a mirror. The darker side is a normal glass [8].

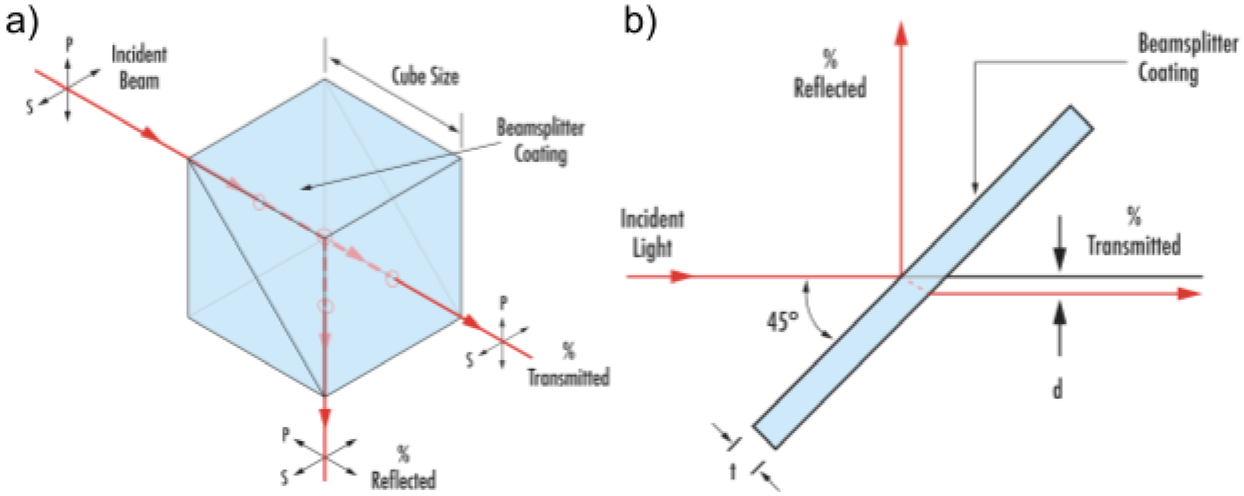

Figure 5: Mechanism of beam splitter cube [9]. a) Beam splitter cube. b) Beam splitter plate

Through further research, the team found that a beam splitter is an essential replacement for the one-way mirror and a crucial element in achieving the success of implementing video relay capabilities into a traditional handheld otoscope. Typically used in cameras, projectors, laser systems, and more, a beam splitter is an optical device designed to divide a beam of light into two or more separate beams. Each of these travels along a distinct path. In this project setting, the beam is the image coming through the specula and the desired image direction is perpendicular to each other, creating two image paths that are 90° [9]. This is done by using a pane of glass that has reflective and transparent coating angled at a 45^0 as shown in Figure 5a-b. Various types of beam splitters exist, each employing specific mechanisms tailored to different applications. Common mechanisms include plate beam splitters, which use a partially reflective coating on a thin glass or quartz plate to transmit and reflect light; cube beam splitters, utilizing a cube-shaped block of glass with an internal partially reflective coating; polarizing beam splitters, which separate light based on its polarization. The choice of a beam splitter type depends on factors such as the application's requirements, wavelength range, and desired optical performance which is discussed later in the materials section. These devices play a pivotal role in the optical systems of the otoscope, facilitating light redirection.

Other crucial components to making this project successful include a micro camera, an LED light, and a battery holder. The camera needs to be small enough to fit within the otoscope body, specifications will be discussed later in the fabrication section. An endoscopic camera is a tool that is employed to capture detailed pictures and videos of hard-to-reach regions. It is commonly used in the medical field but it is also utilized in diverse industries, such as automotive repair, plumbing, electronics, pest control, and security [10]. For this purpose, the team decided an endoscopic camera would be the best option, due to its small diameter for easy fitment, and high imagery quality for proper veterinary examinations [11]. Besides image quality, the camera must also have the correct focus length. By definition, the effective focal length (EFL) is the distance between the rear principal point and the lens's focal point. The team measured the required EFL to be 10 to 12 centimeters according to the quick estimation method provided by the University of Arizona [12]. This is the distance from the camera to the observing area, including the beam splitter and the speculum as well as a 1-centimeter distance from the tip of the specula to the examination areas [13]. An LED light and a battery holder are also needed to ensure proper visibility of the area of interest.

Client Information

The clients, Dr. Lara Tomich and Dr. Amy Nichelason are employees of the University of Wisconsin School of Veterinary Medicine. They came to this group looking for a device that incorporates a handheld eyepiece that also relays a video feed to a faculty member from a distance [14].

Design Specifications

The following design specifications are found in Appendix A. This device needs to be lightweight, comfortable to hold, and easy to work with for new veterinary students to minimize perceptual differences between the lens and camera. This device will include an external light source used for reflection and to assist the camera, as well as video relay ability. The ideal weight of this device is between 0.45 to 0.91 kilograms and its measurements will be nearly 196.48 mm in length, 24.50 mm long on the top head, and 30.92 mm in diameter [15]. These measurements are based upon those of the Welch Allyn Pneumatic Otoscope given to the team by the client. This device should be able to withstand debris within an animal's ear. The shelf life of this device is determined by the proper care. Storage should have a temperature between -20℃ and 55℃ and a humidity limitation of 10% to 95%. The atmospheric pressure limitation of the device will be between 500 hPa and 1060 hPa [16]. By meeting these criteria the device will reduce perceptive differences between the student's view and the faculty member's view on the monitor.

Preliminary Designs

I. One-way mirror

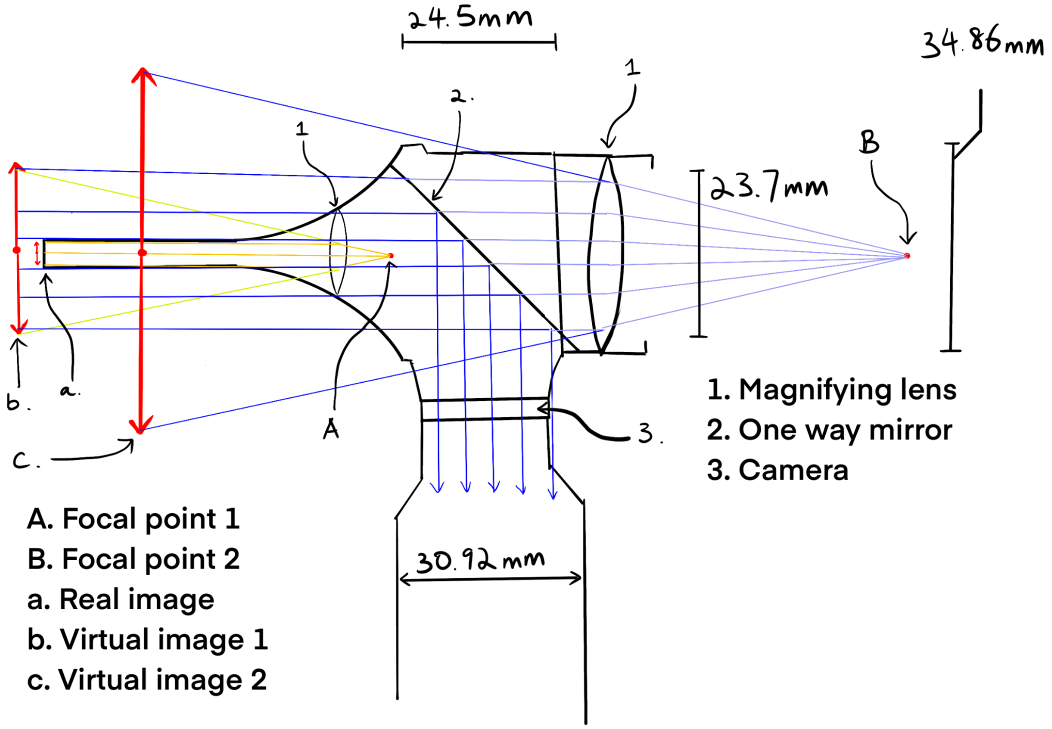

Figure 6: One-way mirror design sketch [17]

This design, Figure 6, utilizes two convex lenses to achieve a magnifying goal. The real image goes through the tip of the specula into the first lens positioned just at the beginning of the otoscope body that projects a larger virtual image to the back. Image 1 then goes through a 45-degree arranged 1-way mirror that reflects 70% of light. The rest travels through another convex lens to enlarge the image for the viewer. This view must keep close contact with the otoscope thus providing a dark environment for the 30% of remaining light to be viewable. The 70% reflected light is captured by a camera below which is transferred to a distant viewer. The light source is located around the camera.

II. Add on module

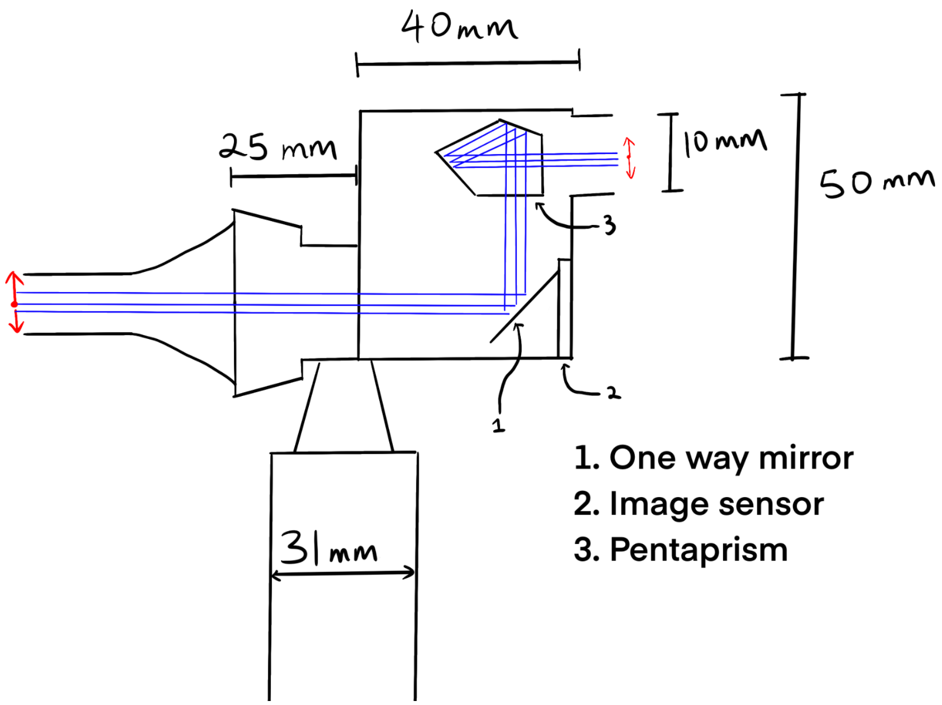

Figure 7: Add on module Design Sketch [18]

This design, Figure 7, is for an external module to be added to a current market handheld otoscope, to integrate video output capacity while maintaining the original optical output. This is to keep the perceptive difference minimal between the digital and optical output and ensure that users can effortlessly transition between these modes. As shown in Figure 7, the otoscope should fit on the handheld otoscope's magnifying lens side. The optical output would first be reflected by a 50 percent polarizing mirror, with part of the image going through the mirror directly to the image sensor. The rest of the image would be reflected upward into a pentaprism, to eventually flip the image up-right and to the visual lens.

III. Hidden Camera

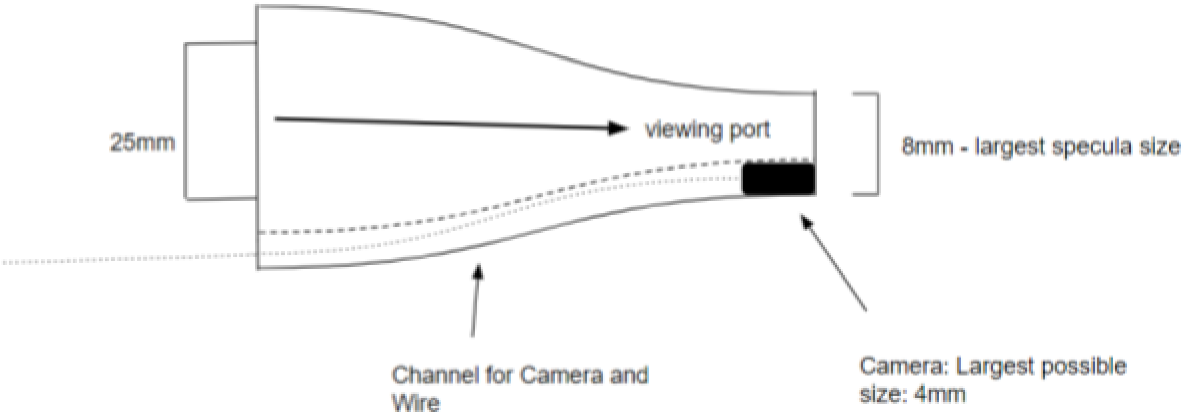

Figure 8: Hidden Camera Design Sketch [19]

This design, Figure 8, uses a camera inside the nozzle attachment that would be affixed around the specula cone. The total diameter of the attachment would be a maximum of 5mm. The camera would have a wired connection to either a video output device (e.g.: laptop, phone, etc.) or a wireless wifi-box that an external device would connect to. Ideally, the camera and wire would not be obtrusive to any form of functionality because the nozzle would essentially act as a second larger specula cone. The wire would be secured onto the otoscope so it is not a disturbance to the user.

Preliminary Design Evaluation

Table 1: Design Matrix

Criteria (Weight %)	**Design1: 1-way Mirror**	**Design 2: Add on Module**	**Design 3: Hidden Camera**
Effectiveness (25)	4.5/5	4.5/5	3.5/5
Ease of Fabrication (20)	2/5	2/5	3/5
Ease of Usage (15)	4/5	2.5/5	4/5
Adjustability (10)	2.5/5	4/5	2/5
Safety (10)	4/5	4/5	3/5
Size/weight (10)	4/5	2.5/5	4/5
Cost (10)	3/5	3/5	4.5/5
Total = 100	**69.5**	**65**	**68.5**

Design Matrix Summary

To evaluate the preliminary designs listed above, a design matrix was developed to rank these designs based on various criteria. Each category for each design was ranked on a scale from 0 to 5. To evaluate the design effectively all aspects of the design had to be considered and the criteria had to receive a different weight based on its importance to the client. The designs were visualized through drawings and the handheld otoscope that was gifted from the client due to the fact the team does not have any prototypes to test at the moment.

The design that scored the highest in effectiveness, ease of usage, safety, size/weight, and cost was the 1-way mirror otoscope. This idea was accepted as the design that would fulfill the client's requirements the best due to its winning categories. One design flaw of this design is the ease of fabrication will be difficult due to the modifications needed on the inside of the otoscope.

The Add-On Module was not accepted as the winning design due to the foreseen difficult fabrication and usage. Based on the client's requirements, the device needs to be usable for first-year veterinary students. This device, due to its large weight and size, would not fulfill these requirements because the add-on module is bulky and would be more difficult to control while used on a live animal.

The Hidden Camera design was not accepted by the group due to its rated effectiveness and adjustability. The hidden camera would require a microcamera to fit inside the specula. This type of camera would be expensive and would not allow for adjustability of the specula size. One aspect of this design the team was fond of, was that it did not involve modifying the inside of an otoscope which decreases fabrication complexity.

Proposed Final Design

The One-Way Mirror design will allow the veterinary student to examine a dog's ear canal while the faculty members can view the same image from a distance on a monitor. This design will minimize the perceptive difference between the two viewers due to the reflection of the light on the mirror. Figure 6, shown above, shows the planned dimensions of the device and the projected head shape of the otoscope. The team plans to use Bluetooth connections between the One-Way Mirror Otoscope and the monitor it is viewed on. To use this device the Bluetooth connection will need to be confirmed, then the student will turn on the light and insert the otoscope into the animal's ear.

Fabrication and Development Process

Materials

The camera is considered the most important piece of the otoscope. The endoscope camera used is the Teslong auto-focus endoscope [20]. This camera has a desired focal length ranging from 17 mm to 30,000 mm and can auto-focus with a maximum resolution of 2560 by 1980. By comparing the manufactured specifications and taking into account that the endoscope camera will not be used for its intended purposes, the team decided the Teslong endoscope fits the desired needs of the otoscope. This is because of its ability to provide a higher resolution and ideal focal length for the otoscope design. The team used a 50R/50T, fifty percent reflection with a fifty percent transmission ratio, beam splitter cube for this project with side lengths of 20 mm [21]. The team determined that the fifty-fifty ratio would result in the most accurate camera image in comparison to the lens image. The side length is determined based on the Solidworks model. A circular magnifying lens with a diameter of 25 mm and a focal length of 100 mm was used [22]. The diameter of the lens was determined based on the model and the focal length was determined based on the average specula length provided by the client. A 3V coin battery with a diameter of 20 mm and thickness of 3.2 mm (CR2023) was used to power the micro LED due to its ease of replacement [23]. Compared to a 9V AA battery, CR2023 is cheaper and smaller in size, thus reducing weight, and fits more appropriately in the otoscope. Other essential components such as LED, button switch, and 3D printing materials were determined based on price and vendor availability. Details of expenses can be found in Appendix E and a more detailed rationale of camera and beam splitter choices can be found in Appendix F.

Methods

Optical Components

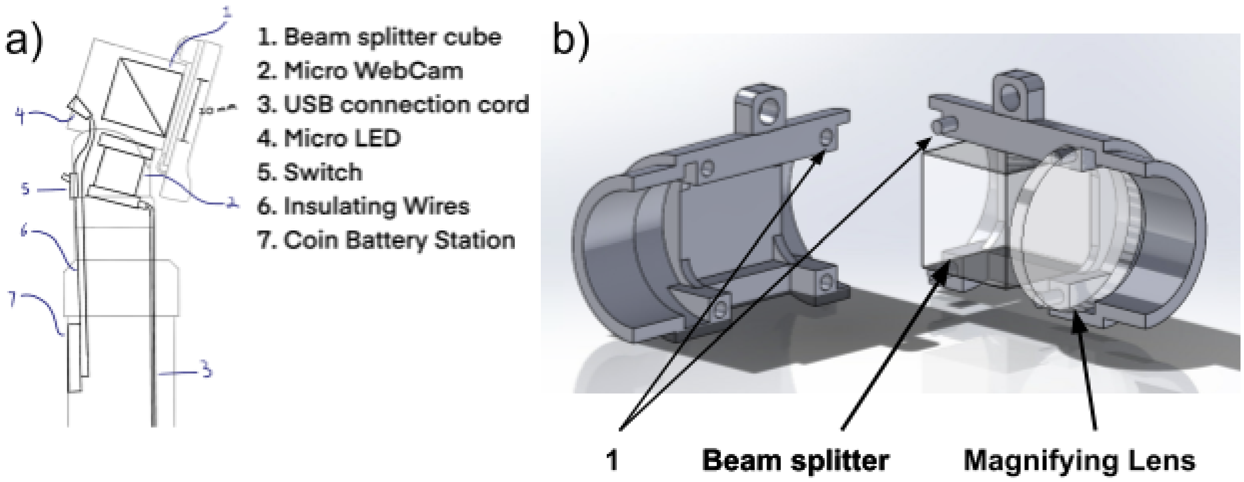

Figure 9: Optical component layout of the otoscope head. a) diagram of accessory components layout. b) 3D visualization of placement of beam splitter and magnifying lens in the otoscope head.

For the design's purposes, the beam splitter cube is positioned at the center of the otoscope head, just a few millimeters from the viewing window. Below the beam splitter, the camera extends up through the otoscope's handle and neck, to ultimately point towards the beam splitter to capture the reflected image. This image is then transferred to a distant monitor via the camera connection cord, as illustrated in Figure 9a, components 1-3. This orientation was chosen as the most optimal, considering the otoscope's shape and allowing each component to fit in naturally with the otoscope. This was to avoid unnecessary components and structures that could contribute to bulkiness and undesired weight. The original placement of the magnifying lens was behind the otoscope head, right next to the viewing window. However, this orientation is not ideal as it hinders the magnification of the camera. Therefore, to enable effective magnification for both the otoscope user and the camera, the magnifying lens must be positioned between the beam splitter and specula, as depicted in Figure 9b. To ease the assembling and accurate enclosure of the lens and beam splitter within, four pairs of cylindrical rods and extruded cuts were made on each side of the otoscope head, as denoted as 1 in Figure 9b. This design keeps unnecessary movements of the beam splitter and lens in the otoscope.

Otoscope Body

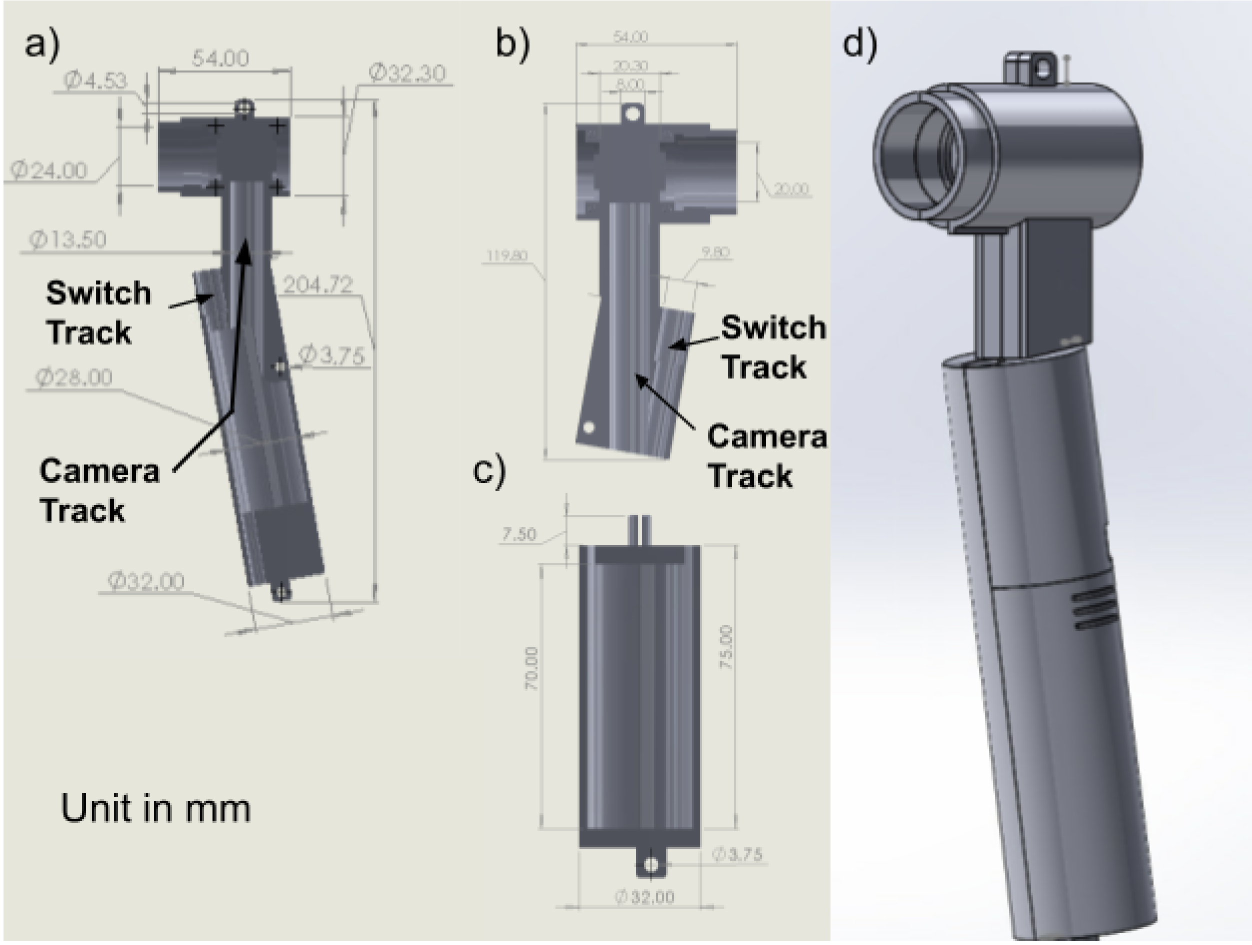

Figure 10: Otoscope SolidWorks. a) Component A -the otoscope body. b) Componen B- Symmetrical cover. c) Component C- Battery case. d) Assembled device

The otoscope's main body is separated into three main components, each modeled individually in the Solidworks images in Figure 10. The reason for this distribution of parts is for a more efficient assembly. During the early stages of this project, a beam splitter, lens, camera, switches, and batteries all needed to fit inside the otoscope. Due to these constraints, the essential accessories must be easily accessible. Thus the team came up with a way to enclose accessories by splitting the otoscope into a symmetrical left and right part. The idea is that when all the accessory parts are put in place in one half (Figure 10a), the other half (Figure 10b) will snap right onto the first half and screws can be used to securely tighten both sides with all accessories inside. Throughout the modeling process, both halves were done synchronously to avoid dimension errors. Notice in both Figure 10a and 10b, that two extruded cuts were made. One is a camera track for the placement of the endoscope camera while the other is for the button switch. All internal dimensions are strictly followed by the measurements made for each accessory component including the beam splitter, lens, camera, and switch. Due to minor 3D printing errors, a tolerance of 2-3 mm was also included in most dimensions. As mentioned earlier, the battery is placed in the handle and can be replaced when it dies. However, removing the entire half is not ideal because that results in the exposure of all accessories inside, for example, the beam splitter and lenses, when reassembled may cause damage to these optical components. This would result in disruption and lower quality of image feed. Due to this consideration, one-half of the otoscope is split into a top part and a bottom part. The top part retains the features of the symmetrical part and is screwed together permanently, but it is also able to be opened if any optical part such as the beam splitter or lens needs to be changed. The bottom part acts as a case for the battery and can be taken off easily, similar to if a TV remote needed a battery change (Figure 10c). Another key feature of this otoscope model is that the otoscope head was tilted to an angle of 10° perpendicular to the otoscope handle. This was a feature on the original Welch Allyn Otoscope [15]. After all parts are finalized on Solidworks, the STL file is taken to the MakerSpace of UWMadison to print on the Ultimaker (Figure 10d) [24]. During this process, numerous small modifications to dimensions and internal designs are made to better cooperate with the accessories component. To address this, see Appendix D for supplementary design images from past modifications. The final printed pieces were assembled to create the final prototype.

Camera Cord Orientation

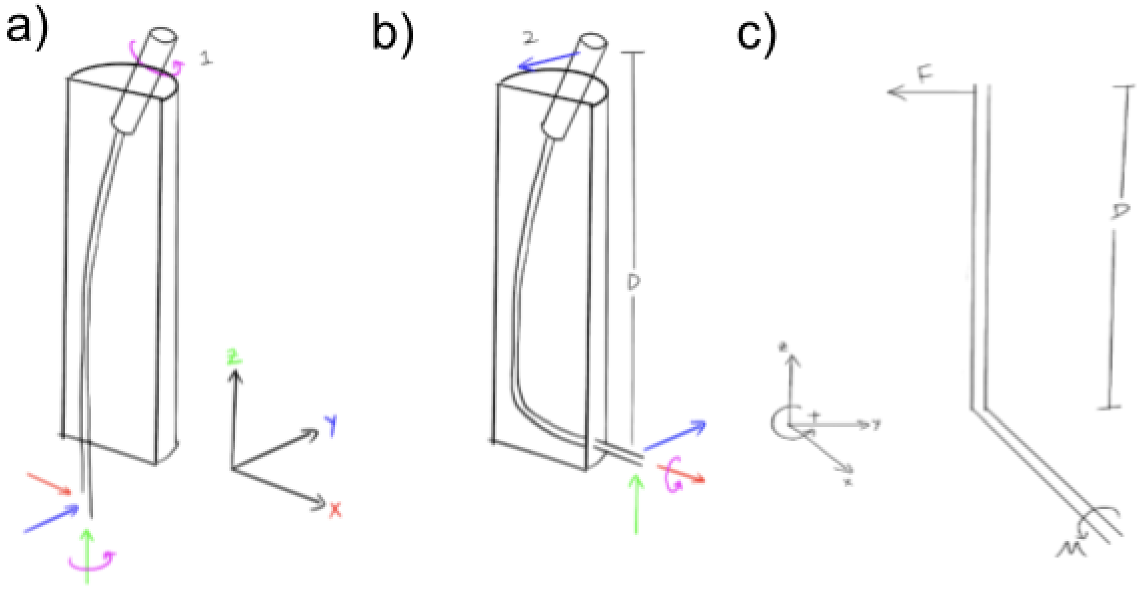

Figure 11: Wire orientation. a) Design 1-Straight through orientation. Camera cord exits through the bottom of the handle b) Design 2-Angled orientation. The camera cord exits through the side of the handle. c) Simplified mathematical explanation of orientation of design 2. The semi-rigid camera cord is instead assumed to be completely rigid.

Due to the semi-rigid camera cord used in the design, two orientations of the camera wire were considered during the design process. Design 1, shown in Figure 11a, has the wire coming straight down and out from the bottom of the otoscope handle. Design 2, shown in Figure 11b, demonstrates the wire coming out at a nearly 90-degree turn through the side of the handle. This was considered due to the internal spin of the camera that results in a wrong orientation of the camera. In Design 1, the forces that are generated by the user can be turned into 4 categories, forces acting in x, y, and z, and moment in the z-axis. There's no moment in the y or x-axis because the wire is reinforced by the handle in those directions. Forces in the x y and z directions can all be accommodated and compensated by an opposite reaction force provided by the handle itself as support thus these forces don't create any motion or rotation to the camera. (Note, force in z direction is reacted directly to the beam splitter which is not illustrated in this drawing). All these reactive forces keep the camera from heavy movements that result in the wrong orientation. However, the moment in the z-direction, noted in the pink arrow in Figure 11a, has no reaction force on the camera, thus creating a moment (labeled as 1 in Figure 11a) identical in direction and magnitude to the camera. This transferred moment is what creates a spin on the camera thus tilting the orientation on the screen. In design 2, viewing from the axis, the force that is generated by the user is similar to design 1, in 4 main directions, forces acting in x, y, and z and moment in the x-axis. There's no moment in the y or z-axis because the wire is reinforced by the handle in those directions. Forces in the x, y, and z directions are all compensated by an opposite reaction force provided by the handle itself as support thus these forces don't create any motion or rotation to the camera. (Note, force in x direction is reacted by the internal structure of the 90-degree turn of the wire that is not illustrated on the drawing). All these reactive forces keep the camera from heavy movements that result in the wrong orientation. There's also the moment in the x direction (shown as pink in Figure 11b), through the laws of moments, F=MD (M=moment observed, D=distance from the axis of rotation to the point force), will create a force that is proportional to the moment observed, and the distant from the axis of rotation to the point of the force (camera). As shown in Figure 11c along with Equation 1a-b. Such a moment will need a reaction force of -M/D to compensate for any changes to reach static equilibrium. However, unlike design 1, design 2 transforms the observed moment into a point force (labeled as 2 in Figure 11b) that can be resolved by the internal structure of the otoscope handle. This reaction force is labeled F and can be written as -M/D. Thus no external force can act on the orientation of the camera. This resolved the problem of the spin of the camera that creates a tilt on the screen.

a)

$$\sum M_x = 0$$

b)

$$M + FD = 0$$

$$F = -M / D$$

Equation 1a- Sum of moments at equilibrium. 1b- Solved for F using an equilibrium equation.

From analysis and discussion in the team, design 1 needs extra support on the camera such as glue to keep the camera from spinning due to the external moments. Design 2 solves the problem with mechanical structures. However, design 1 is ergonomically efficient for use since the wire exits the handle at the bottom. Design 2 will create obstructive interference to the user due to poor ergonomics. Due to these considerations, the more ergonomically favored design 1 was chosen.

Lighting

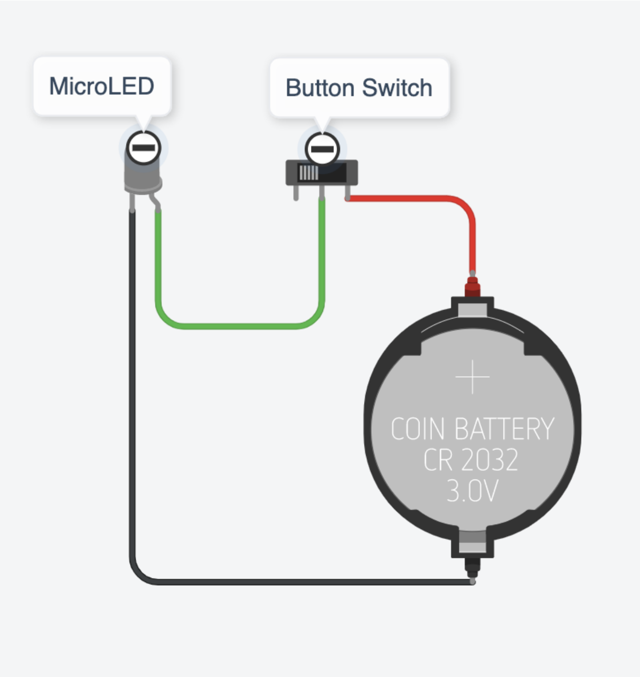

Figure 12: LED Circuit Diagram, TinkerCAD

To securely mount the light source and its necessary accessories, the coin battery holder, button switch, and LED were connected by soldering, ensuring a secure and reliable connection, as shown in Figure 12. The negative end of the coin battery was directly connected to the negative end of the micro LED, and the positive end of the coin battery was connected to the switch and then further linked to the positive end of the micro LED light. Afterward, these components were fitted inside the otoscope body. The battery holder was placed at the bottom of the otoscope body within a specially designed slot, with a modified cap allowing an easier battery-changing process. The thoughtful design allows for the convenient opening of the battery holder, exposing the location when the Component C-Battery case component is removed. To incorporate the LED into the otoscope's functionality, its wires were extended outside the otoscope body, securely attached to the specula, and neatly affixed with tape. The LED light itself was strategically positioned near the opening of the specula, ensuring its illumination was directed towards the front, optimizing visibility during use.

Final Prototype

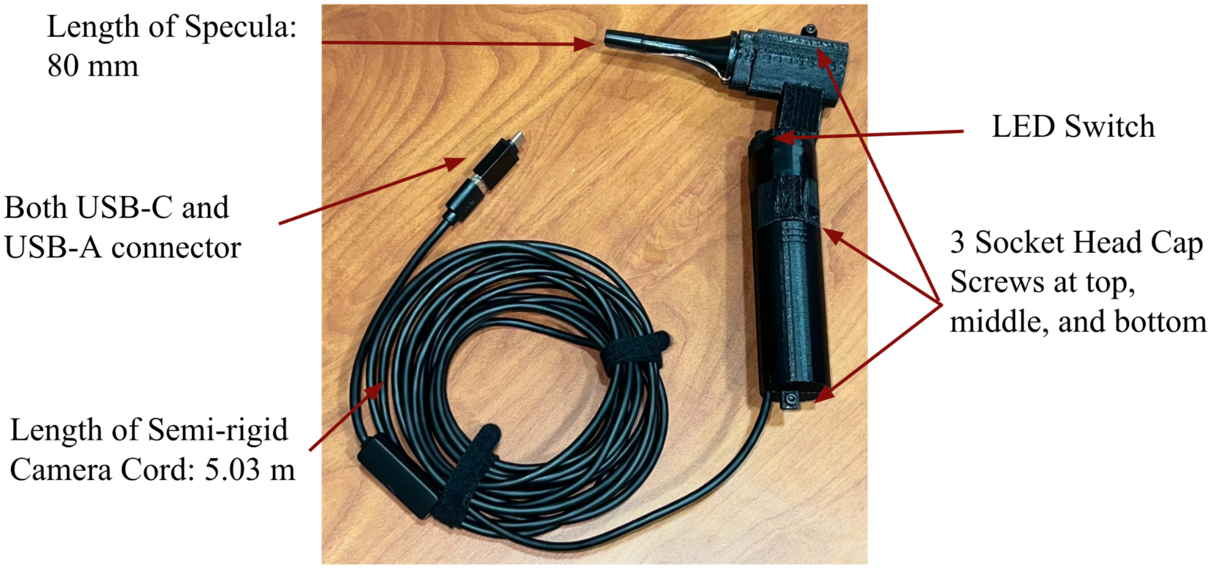

Figure 13: Final Otoscope Prototype

The final prototype of the otoscope was accomplished by assembling all three components along with accessories, as shown in Figure 13, which consists of the main otoscope body, an extended camera cord, and a speculum. This device uses the Teslong endoscope camera which comes with both USB-C and USB-A adaptors and 5.03 meters of semi-rigid camera cord. As shown in Figure 14 below, the inside of the otoscope has the following main components: battery holder, magnifying lens, beam splitter cube, endoscope camera, button switch, and additional supporting wires along with the camera cord. The arrangement of the accessories follows the extrusion cut made on the otoscope body and fits well. Most components fit properly without room for unwanted movements, except for the endoscope camera due to its shape which is taped to avoid sliding movements.

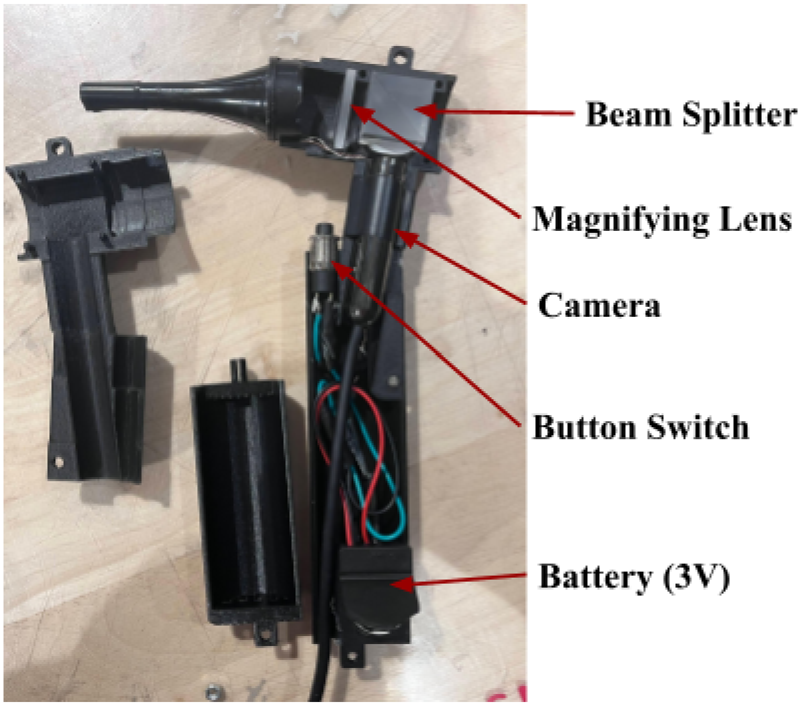

Figure 14- Internal Structures and Components

Testing

Preliminary Experimentation

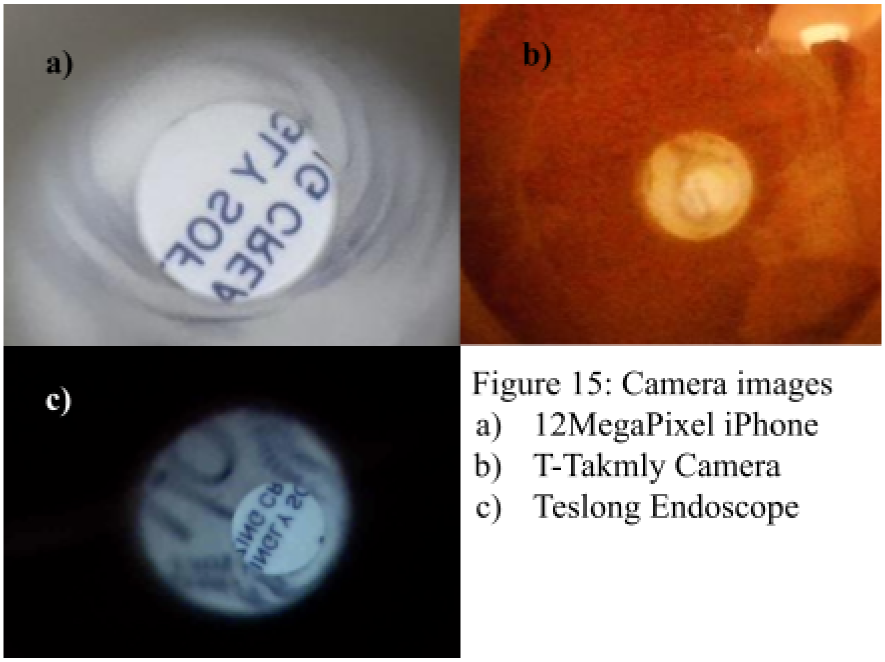

Figure 15: Camera images
a) 12MegaPixel iPhone
b) T-Takmly Camera
c) Teslong Endoscope

During the camera otoscope selection process, testing was conducted to see how well different cameras would be able to capture the incident image being reflected from the beam splitter. Testing on prospective cameras was performed by placing the camera options directly underneath the beam splitter, pointing at a 90-degree angle with the orientation of the specula. To look at the video feed that each camera could potentially deliver, they were evaluated based on the quality of the images captured. As a reference point, the imagery obtained from a 12-megapixel camera with automatically adjusting focus (iPhone 13) was employed, as illustrated in Figure 15a. This served as a representation of the ideal quality of the image feed, as the image is bright, clear, accurate, and in focus, despite this, its larger size and high cost made it unsuitable for this application. For the otoscopic cameras, the T-Takmly camera was first fitted in the otoscope, and the image is found in Figure 15b. The imagery has good brightness but lacks the correct contrast and definition the device needs. It was decided that the T-Takmly camera quality was unsatisfactory, most likely due to having an incorrect focal length, which is non-adjustable on the camera. The next camera the team tested was the Teslong endoscope camera. This 5-megapixel camera boasted a resolution of 2560 by 1440 and had autofocus capabilities, which the team hoped would yield better images. The image taken, found in Figure 15c, resulted in far better image quality, clarity, and brightness than that of the T-Takmly. The team deemed the camera satisfactory and opted to move forward with the Teslong camera for the final prototype. Slight remodeling of the otoscope interior was done to accommodate the size and shape of the Teslong camera.

Final Prototype Testing

To test the final prototype, the team felt it sensible to ask participants to practice operating the device. The team communicated with Lara Tomich to set up a meeting at the School Of Veterinary Medicine. This allowed the testing of the prototype to proceed with more experienced users of an otoscope. In addition to testing at the vet school members of the team also conducted testing with engineering students around campus. Before conducting testing for the final prototype, the team acknowledged that apart from the qualitative data, having quantitative data would also be very valuable. To do this the team designed a survey, outlined in Appendix B, that was meant to not only identify flaws and potential improvements but also to provide quantitative results.

However, the overarching goal of the final prototype testing was to determine whether or not the final prototype meets the product design specifications detailed in Appendix A. With that in mind, the team specifically designed the testing survey to evaluate how well the final prototype adhered to the *Performance, Accuracy/Reliability, Ergonomics, Size, and Weight* design requirements that were detailed in Appendix A. A majority of the questions on the testing survey explicitly tested for the *Performance* and *Accuracy/Reliability* requirements. This was done by asking the participants to rank certain criteria that the team felt best contributed to meeting the aforementioned requirements. Such criteria included brightness, visibility, video clarity, and both lens and video magnification. Additionally, Questions 11 and 13 of the testing survey specifically pertained to fulfilling the *Ergonomics,* and *Size/Weight* requirements, respectively.

Results

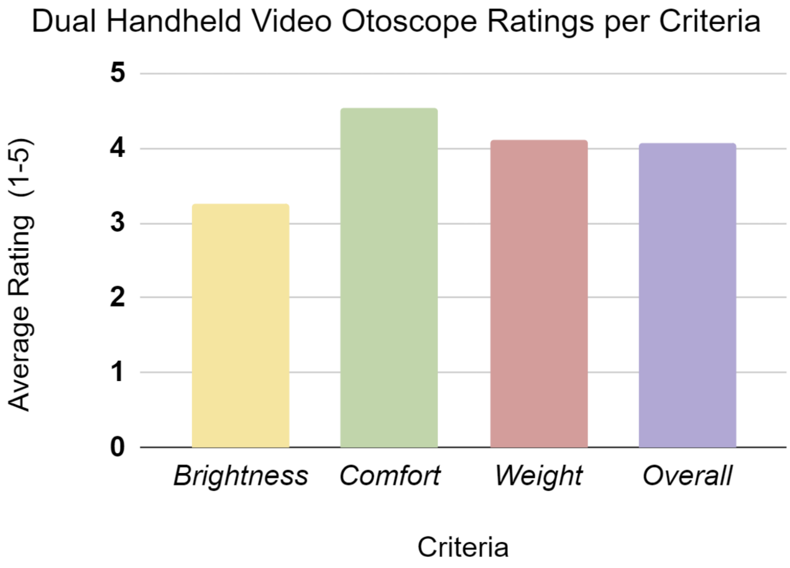

Figure 16: Average rating of criteria based on date from questions 10, 11,12, and 14 in Appendix C

Based on the testing completed in Appendix B the following results were obtained and raw data was placed in Appendix C. In Figure 16, shown above, data from questions 10, 11, 12, and 14 were averaged and placed on the graph. The purpose of this graph is not to compare values but for a straightforward display of data.

Overall the brightness of the light source was given an average of 3.52 with a standard deviation of 1.16. Participants were given the option to rate this category on a scale from 1 to 5, too dark to great lighting respectively. By looking at Figure 10C in Appendix C the team was able to determine that the light source values ranged through all number choices and a mean value does not properly represent the inaccuracy of this category. This category having the lowest average out of all criteria tested showed the changes that needed to be made to the LED source.

The comfort level of the device was given an average rating of 4.52 with a standard deviation of 0.79. Although this standard deviation is lower than that of the brightness of the light source, it is still fairly high for an accurate average. This is encountered due to the small range of numbers participants were able to choose from. Comfort resulted in the highest average out of all criteria tested, meaning the team does not have many improvements to make regarding this aspect of the design. The raw data from this category is shown in Figure 11C in Appendix C.

The participants were asked to rate the prototype based on its weight and size, resulting in an average of 4.35 with a standard deviation of .71. Figure 12C in Appendix C shows that results ranged from 3 to 5. Due to the average being higher than that of the brightness of the LED, the team does not have large-scale plans to increase this average at the moment.

Finally, the last bar in Figure 16, shows participants gave an average rating of 4.06 with a standard deviation of .43. The standard deviation shown for this criteria gives the team an accurate idea of what the majority of participants believe the otoscope's overall rating is. No tests were conducted to determine correlation and causation between the results of the survey.

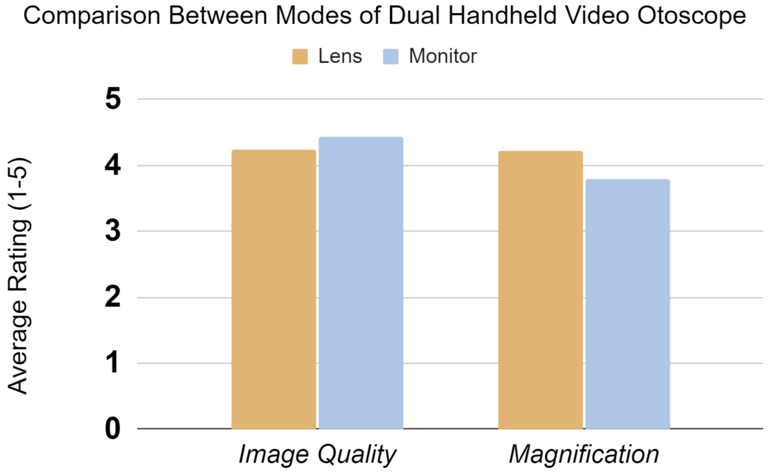

Figure 17: Comparisons of modes of otoscope viewing from questions 5, 7, 8, and 9 in Appendix C

In Figure 17, shown above, the raw data used to produce these averages is located in Appendix C. The two modes of otoscope viewing in comparison are through the lens and on the monitor. The purpose of this graph is to compare two major criteria that the team needed to compare to the preliminary design specifications.

The first criterion the team compared was the image quality of the lens versus that of the monitor. Image quality through the lens was rated an average of 4.24 with a standard deviation of .83, with raw data located on Figure 5C in Appendix C. Image Quality of the monitor was given an average of 4.43 with a standard deviation of 0.66, individual participant answers located on Figure 7C in Appendix C. Due to the average of the monitor viewing mode being higher and having a lower standard deviation, the team concluded that viewing on the monitor produces a superior-quality image.

The second criterion the team compared was the magnification of an image through the lens versus the magnification of the image on the monitor. The participant data was averaged from Figure 8C in Appendix C, to give an average of 4.22 and a standard deviation of 1.04, for the magnification of an image through the lens. Figure 9C in Appendix C showed the team that the magnification of the monitor received a lower average of 3.78 with a standard deviation of 1.20. The values shown in this comparison have similar standard deviations meaning the accuracy of these results are similar in accuracy. Overall the magnification of the image through the lens has a higher average rating.

As shown in Figure 15C, participants were asked to choose which otoscope (current market otoscope versus dual device prototype) they preferred for teaching purposes. 76.9% of participants chose the dual device prototype. To improve this value the team will discuss the implications of the results and future work in the following areas of the report.

Discussion

Based on the testing the team has completed and the results returned, the team will discuss how these values relate to the preliminary design specifications in Appendix A. Then the evaluation of these results will lead to a discussion of the necessary changes needed for a high-functioning prototype.

When discussing preliminary designs with the clients, they did not have a preference for a light source. Their main desire was for the light to illuminate the ear canal enough for students and instructors to view the ear canal. Based on the average shown in Figure 16, 3.52, this score did not meet the requirements. Verbal feedback was given in Appendix C under questions 13, 17, and 18 that the brightness of the LED needs to increase and its location needs improvement.

Comfort and Weight/Size of the device were given a fairly high rating of 4.52 and 4.35 respectively. The team's preliminary design specifications described these criteria in Appendix

A, in which the device will be comfortable to hold in a hand. This would be done by fabricating the device to have similar dimensions as the current market otoscope gifted to the team from the client, a Welch Allyn Pneumatic Otoscope [15]. The team completed the goal by having similar dimensions and by having a device weighing below .91 kilograms. Changes may be made to improve these averages such as 3D- printing with a smoother material and removing the camera cord.

Shown in Figure 17, the modes of image viewing on the prototype otoscope for two criteria are shown. The first comparison shown was for image quality through the lens and on the monitor. Image quality was ranked higher on the monitor compared to the lens, which aligns with the team's preliminary design specifications. In early discussions with the client, her desire was for the monitor quality to be equal to that of the lens, and for anatomical identifications to be made. The team tested this connection to the preliminary design specifications by asking participants to identify various shapes, colors, or numbers while viewing through the lens and monitor. The resulting data is shown in Figures 3C and 4C in Appendix C, with 100% of participants identifying their given shape, color, or number correctly. Improvements may be made by increasing the focal length of the lens and by purchasing a camera with a higher pixel count.

Figure 17, shows the second criterion, magnification, between the lens and monitor view. Magnification was rated higher in the lens than in the monitor. This does not align with what was expected from the preliminary design specifications. The client desires the magnification of the image through the lens to look identical to that on the monitor. The monitor viewing screen showed a large amount of black area around the simulated ear canal. Verbal feedback listed in Appendix C, under questions 13, 17, and 18, told the team that improvements to the viewing screen are needed. Improvements are needed on the monitor screen for the optimal viewing experience for instructors.

By analyzing the results and connections to the preliminary design specifications the team believes that the overall average of the otoscope rating would increase.

The team has thought of future aspects of the device and how it can be used in various applications. One proposal is supporting telediagnosis. Since the digital image can be viewed live and recorded, with an internet connection added, the design not only allowed for tele-diagnosis by distant health professionals but potentially also through AI [25, 26]. Such implementation might be beneficial to places with limited veterinary healthcare resources. This diagnosis method supports the ongoing trend of artificial intelligence in healthcare and might bring significant advancement in the field.

Conclusions

Current handheld otoscope designs either cannot stream a video feed of the student's view to a remote device or they utilize a video digital view of the area of interest instead of a traditional lens view, which is essential for simulation training. The team's goal is to combine these two features into one handheld otoscope to aid in teaching. Throughout the development process, the preliminary designs, including a one-way mirror system and an add-on module, provided valuable insights into potential solutions. After careful consideration of all designs using a design matrix, the one-way mirror design is decided to be the best solution. Throughout the development of this design, the team found multiple beneficial changes such as: using a beam splitter cube instead of the one-way mirror and using an endoscope camera in place of a traditional camera. The iterative design process, 3D printing, and careful modeling contributed to the successful creation of a functional otoscope that meets the clients' expectations. The team's survey was sent out to multiple participants with various backgrounds across the campus to gain valuable insights and data surrounding different features of the prototype. Testing the prototype revealed positive aspects, with users praising comfort, size, and overall usability while preferring the prototype over traditional otoscopes. Certain areas, notably LED brightness and monitor magnification, identified room for improvement. With some downsides to the prototype, the overall performance of the product meets the goal set by the team and created an innovative design that could serve practical and effective instructional use here at the UW Madison School of Veterinary Medicine as well as at other teaching institutions. Moreover, even serving as a foundation for future innovations and designs that attempt to tackle a similar issue, is in itself a worthwhile endeavor. In future iterations, improvements in LED technology and adjustments to the monitor can enhance the otoscope's performance. Additionally, exploring potential applications such as telediagnosis and integration with evolving healthcare trends could further extend the otoscope's impact. Lastly, changes in the design such as creating a Bluetooth version without the stiff endoscope wire could vastly improve the prototype.

In conclusion, the dual-device prototype otoscope represents a significant advancement in addressing the limitations of traditional veterinary otoscopy. The iterative design process, user-centric focus, and attention to client specifications contributed to a successful prototype. While challenges remain, the positive feedback and identified areas for improvement provide a solid foundation for future refinements and the potential expansion of the otoscope's applications in veterinary medicine. It is incontestable that innovation is not a product of any sole person or group, but rather a culmination of effort and passion directed towards a common goal of advancement.

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Acknowledgments

Dr. Lara Tomich

Dr. Amy Nichelason

Professor Justin Williams

Dr. John Puccinelli

Appendices

Appendix A: Product Design Specifications

Dual Handheld and Video Otoscope - BME 200/300 Section 310

Product Design Specifications
September 21, 2023

Team: Grace Boswell, Sam Tan, Bobby Fang, Jose Ramirez, Declan McHugh, and Zakki Mirza

Client: Dr. Lara Tomich and Amy Nichelason

Advisor: Professor Justin Williams

Function:

A typical handheld otoscope consists of three main parts: the head, the tail, and the speculum. The speculum is a thin tube that inserts into the ear canal of animals with a light source at the tip. This part of the otoscope is designed to be able to comfortably create light pathways to go through and direct lights into the head component of the otoscope. The head of the otoscope is a box with a magnifying lens, which is usually convex, that projects a virtual enlarged image of the ear canal to the observer. The tail of the otoscope is for holding, and storage for camera and other essential processing components of the otoscope. Video otoscopes come in a variety of designs. Without the need for a magnifying glass, a video otoscope can be smaller in size. The Dual Handheld and Video Otoscope is needed to integrate functions of the video otoscope into a typical handheld otoscope for distant viewers. While maintaining the features and the three main parts of a handheld otoscope, a digital camera is needed to feed live.

Client requirements:

- The otoscope resembles features of a traditional handheld otoscope (lenses)
- The otoscope has a video relay ability
- External Light Source
- Maintain expenses below the budget
- Capable of using currently existing speculums

Design Requirements:

1. Physical and Operational Characteristics

    a. *Performance requirements:* The redesign of the handheld otoscope must meet basic otoscope features, including allowing light to emit, reflect, and gather back to the viewer. The video relay to a distant viewer must be stable, and smooth. Although no requirements from the client, the resolution and framerate of the camera should maintain industry specifications for a video otoscope at a sensor resolution of 1280 x 1024 and frame rate of 30 FPS [1].

    b. *Safety:* During student examination, a trained handler or veterinary technician should also be present all the time of the examination to assist with collecting data and analysis on performance. This can be the exam instructor as the distant viewer or someone familiar with the process and the device. This is to avoid injuries for both students and the animal subject during the process. The otoscope should also not consist of exposed electrical components and potentially sharp edges that could cause harm to both student and animal subjects [2]. Users or students need to check the basic functions and each part of the otoscope to make sure the otoscope is in functional shape and each component on the otoscope is working to its intended function only, before the use of animal subjects and handled with care to avoid animal abuse. Users or students also need to consider examination duration to avoid overheating from the light source and possible damage to camera functions.

    c. *Accuracy and Reliability:* Magnifying lenses of the otoscope should accurately enlarge the real image. Image through the lens should resemble similar details to the camera-captured images. A minimum of 50 percent accuracy should be achieved when two images overlap and are compared.

    d. *Life in Service:* Otoscopes tend to have long lives in service, the product should run 10,000 exams without major failures. The battery life should be sustained one day in a vet clinic each time fully charged if batteries are used.

    e. *Shelf Life:* Power off, disconnect all electrical connections when not in use, and store them properly. If batteries are used, store them in a dry environment. Storage temperature limitation between -20℃ and 55℃, humidity limitation of 10% and 95% [3].

f. *Operating Environment:* The otoscope operates between the temperature limitation of 10℃ and 49℃, humidity limitation of 30% and 90%, and atmospheric pressure limitation of 500hPa and 1060hPa [3].

g. *Ergonomics:* The device will feature a comfortable grip, intuitive controls, and an optimally balanced weight distribution to reduce strain on the user's hand and wrist. The product should not be bulky and avoid sharp edges and corners for user comfort. Additionally, the ergonomic design will take into account the ease of cleaning and maintaining the otoscope to uphold the highest standards of hygiene in clinical settings.

h. *Size:* The size of the otoscope will be based on the size of the otoscope gifted to us by the client. The brand of the otoscope is Welch Allyn Veterinary Pneumatic Otoscope [4]. Its measurements are 196.48 mm in length, 24.5 mm long on the top head, and 30.92 mm in diameter. Different-sized ear speculums are placed at the front of the otoscope. This device will be portable because it will be used for everyday use.

i. *Weight:* This device will range from 0.453592 to 0.907185 kilograms based on the materials chosen for the camera and video transmission to the monitor. This device needs to be lightweight due to students having to carefully examine dogs with it.

j. *Materials:* 3D printers from the UW maker space will be used to print 3D prototypes of the product [5]. The printing method chosen will most likely be FDM/FFF methods. A laser cutter from the maker space will be used ideally. The laser cutter will be the Universal ILS9.150D [6]. An ESP-32 CAM module along with a 75mm OV2640 is the current solution for the replacement of the digital camera portion of the tail [7].

k. *Aesthetics, Appearance, and Finish:* The appearance and finish should remain mostly similar to currently used ones for recognizability.

2. Production Characteristics

   a. *Quantity:* One or two. More upon request by the client.

   b. *Target Product Cost:* The cost of a typical video otoscope on the market is relatively inexpensive, around $25.99 to $49.99 [8]. Although the client does not have a target cost of the product, maintaining the cost relatively close to the market price is ideal and friendly to all labs and teaching faculties.

3. Miscellaneous
    a. *Standards and Specifications:* The product will not be mass-produced, so there are no manufacturer-required standards. According to the FDA, otoscopes fall into the generic category and do not need FDA clearance. Manufacturers are required to register their devices. [9]

    b. *Customer:* There is a slight preference for the camera feed to be wirelessly connected to the monitor/viewing device, however, it is completely adequate to have a wired connection for the video feed. Additionally, a recording function to be able to review footage is desirable. Lastly, there is a preference for having the viewing experience be on a monitor rather than a cellular device.

    c. *Patient-related concerns:* The otoscope cannot harm the patient in any way and must be as comfortable as possible for the user and patient while being used. The patient should react the same way as it reacts to previously used otoscopes.

    d. *Competition:* Many video otoscopes and handheld otoscopes are available to purchase online. Their price varies based on functionality. However, these designs are often for human use, and options for animal otoscopy are not often available to pick and choose from. Out of those available, some are either handheld otoscopes with no video feature, or video otoscopes that aren't handheld for student examination. One competing design is the Wispr Digital Otoscope [10]. This video otoscope is a close replacement for the handheld otoscope and comes with a video function in replacement for the lenses. However, this does not satisfy the lens requirements and is extremely costly considering the teaching faculty and budget for animal exams.

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Appendix B: Experimental Survey

Otoscope Survey

Question 1: Choose one of the following that best describes your position:

Options: Pre-Medical School
Engineering Student
No Affiliation
Pre-Vet School
Vet
Other(Fill in the Blank)

Question 2: Knowledge level of otoscope before this survey:

Options: None/Limited
Used
Shown/Heard about in class
Experienced

Question 3: Were you able to correctly identify the numbers on the sheet? (YES/NO)

Question 4: Were you able to identify the shape/color inside the ear model? (YES/NO)

****** The following 8 questions were asked on a scale of 1 to 5, the designations of 1 and five are provided below the question******

Question 5: How well could you view the inside of the ear through the lens?
“1” denoted “Not well at all”
“5” denoted “Very well”

Question 6: How clear was the video feed of the inside of the ear?
“1” denoted “Not clear/Very blurry”
“5” denoted “Very Clear”

Question 7: Rank the quality of the image on the monitor:
“1” denoted “Very Poor”
“5” denoted “Very Good”

Question 8: Rank the magnification when viewing through the lens:
“1” denoted “Too much/too little zoom”
“5” denoted “Good Magnification”

Question 9: Rank the magnification when viewing on the monitor:
“1” denoted “Too much/too little zoom”
“5” denoted “Good Magnification”

Question 10: Rank the brightness of the light source:
“1” denoted “Too Bright or Dark”
“5” denoted “Great Lighting”

Question 11: Rank the comfort of the handle:
“1” denoted “Very Uncomfortable”
“5” denoted “Very Comfortable”

Question 12: Rank the size/weight of the device:
“1” denoted “Very heavy”
“5” denoted “Lightweight”

Question 13: What noticeable drawbacks were there with the dual device in comparison to the video otoscope? *(Only answered by those who had video otoscope experience)*

****** The rest of the questions were categorized as the Post Questions******

Question 14: Overall prototype otoscope rating*(From 1 to 5)*

Question 15: Overall current market otoscope rating*(From 1 to 5)*

Question 16: Which device do you prefer?

Options: Prototype Otoscope
Market Otoscope

Question 17: What aspects of the device did you struggle with? (Short Answer)

Question 18: Are there any adjustments that you recommend? (Short Answer)

Question 19: Additional comments? (Short Answer)

Additionally, the following testing procedure was followed for all final prototype testing:

Pre-Procedure:

- The team will be using the most up-to-date prototype
- For testing occurring at the Vet School on Thursday 11/30, the team will use the 3D ear model available at the Vet School.
- For testing occurring outside the Vet School, the team plans to have the participants read small text similar to the preliminary camera testing

Procedure Steps:

1.) Participants will be given the dual otoscope and asked to inspect the inside of the 3D ear model or read the small text provided.

2.) The group member proctoring the testing will ask the participant about the shape and color inside the ear or read the small lettering. The group member will take note of whether or not the shape/color/letter was identified correctly.

3.) The participant can continue to use the lens view of the otoscope to develop a better impression of the device

4.) Once the participant is done using the lens, the group member present will then operate the otoscope and allow the participant to experience the camera view

5.) Once the participant is done with the camera view they will fill out the Google form survey.

Appendix C: Data Collection From Survey

This raw data was collected from the experimental survey in Appendix B.

Question 1:

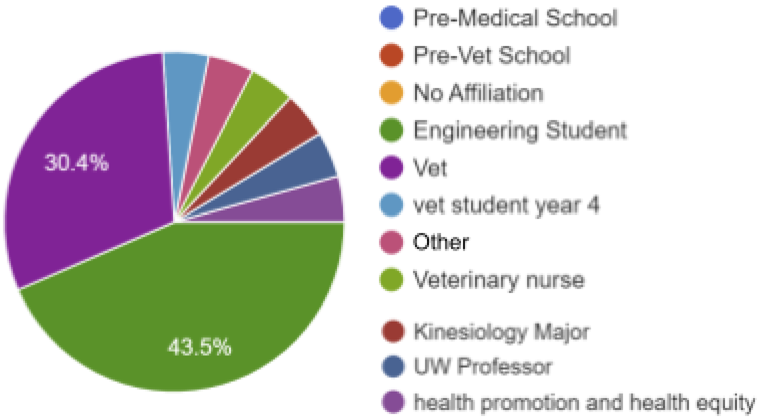

Figure 1C: Title of position of survey participant

Question 2:

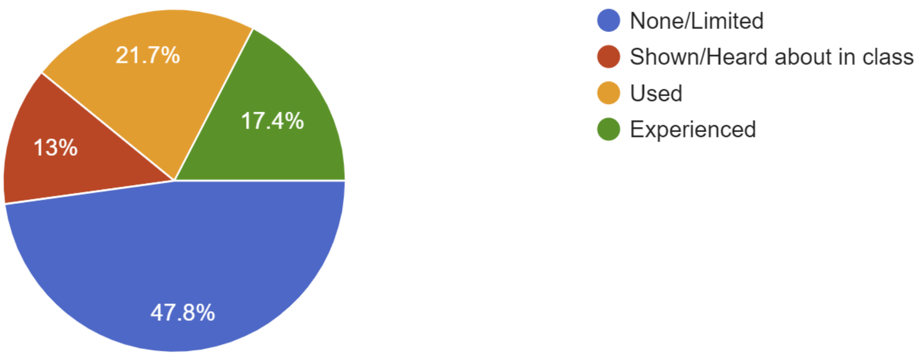

Figure 2C: Knowledge level of an otoscope for survey participants before taking survey

Question 3:

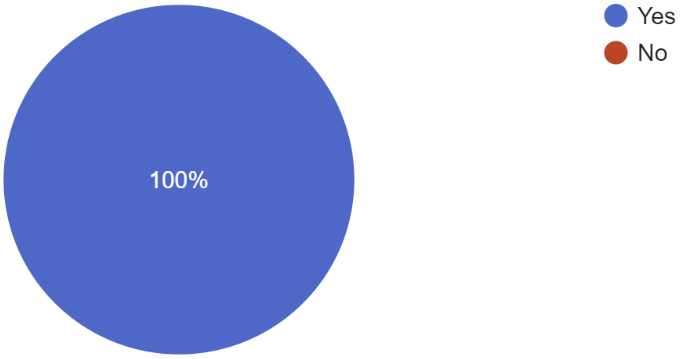

Figure 3C: Percentage of participants that correctly identified the numbers on the sheet

Question 4:

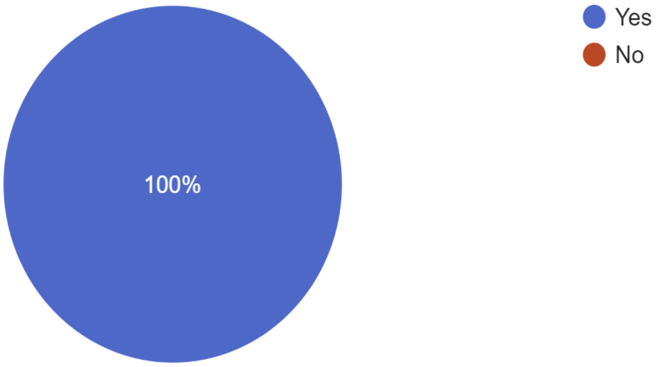

Figure 4C: Percentage of participants that correctly identified the shape/color inside the ear model

Question 5:

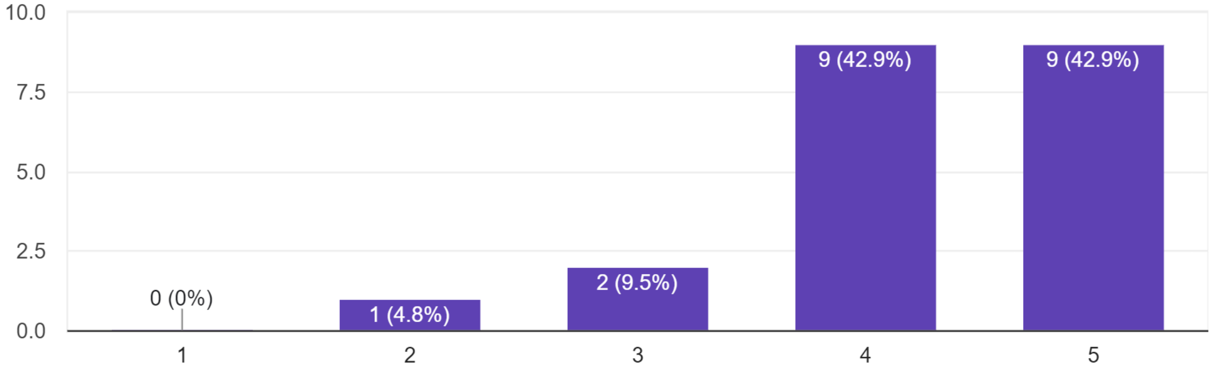

Figure 5C: Ratings from participants based on how well they could view the inside of the ear through the lens

Question 6:

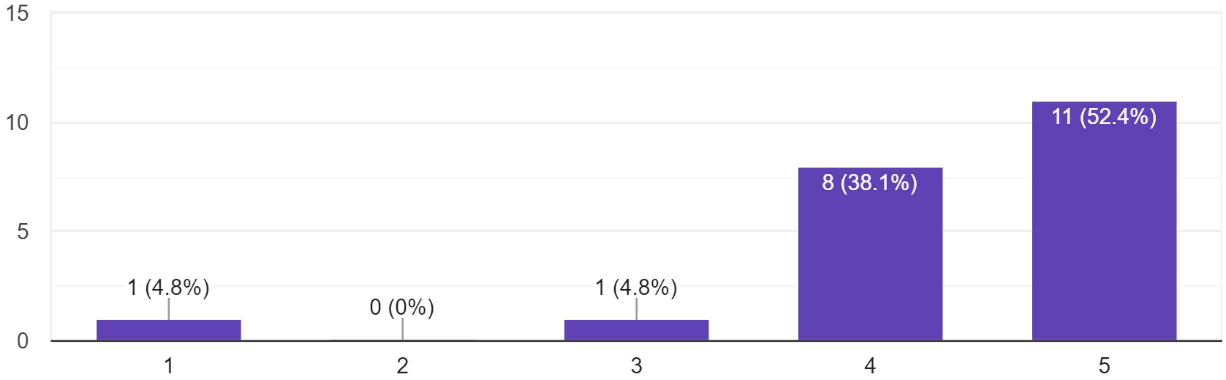

Figure 6C: Ratings from participants based on the clarity of the video feed while inside the ear

Question 7:

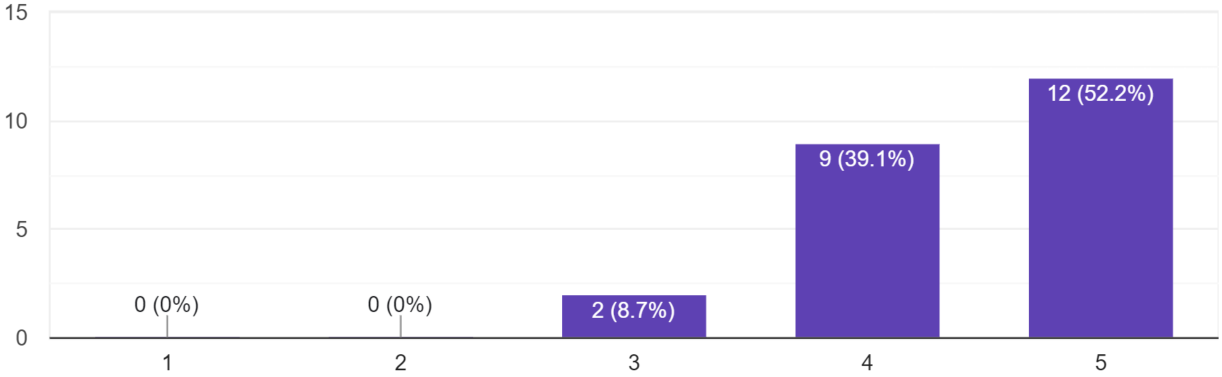

Figure 7C: Ratings from participants based on the quality of the image on the monitor

Question 8:

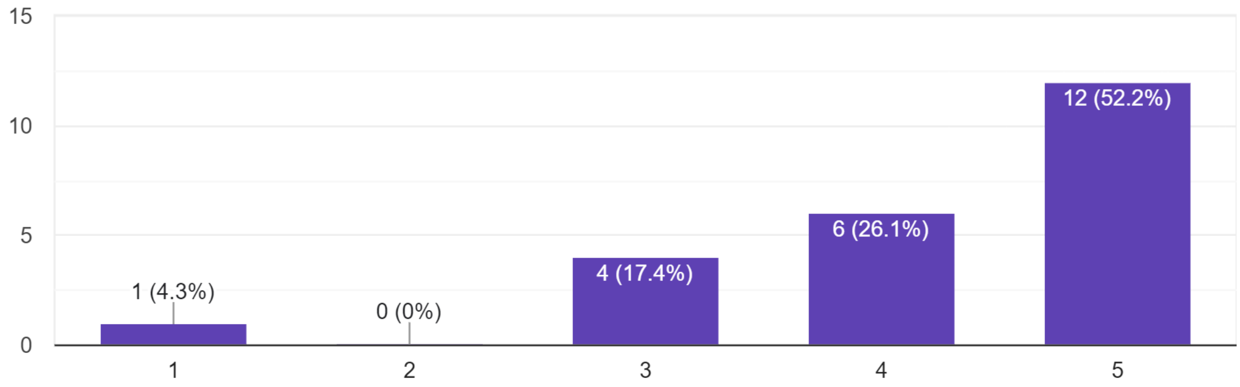

Figure 8C: Ratings from participants based on the magnification of the ear when viewing through the lens

Question 9:

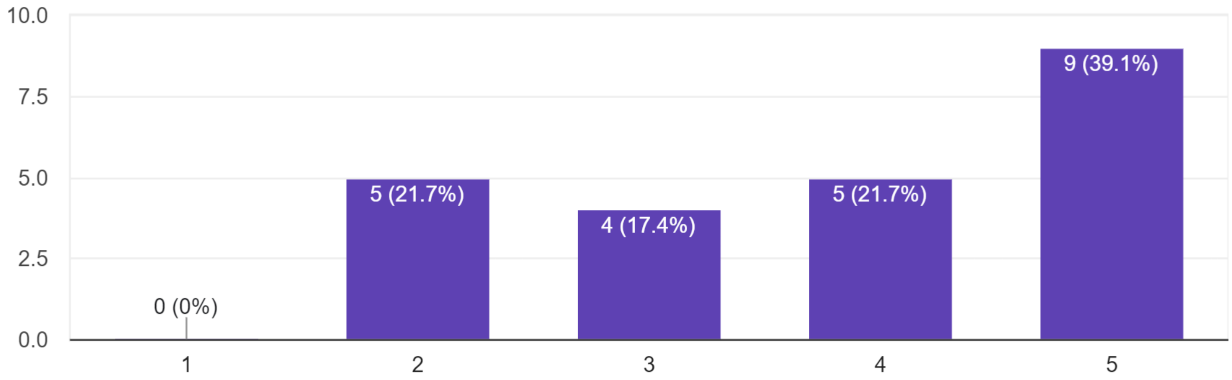

Figure 9C: Ratings from participants based on the magnification of the ear when viewing on the monitor

Question 10:

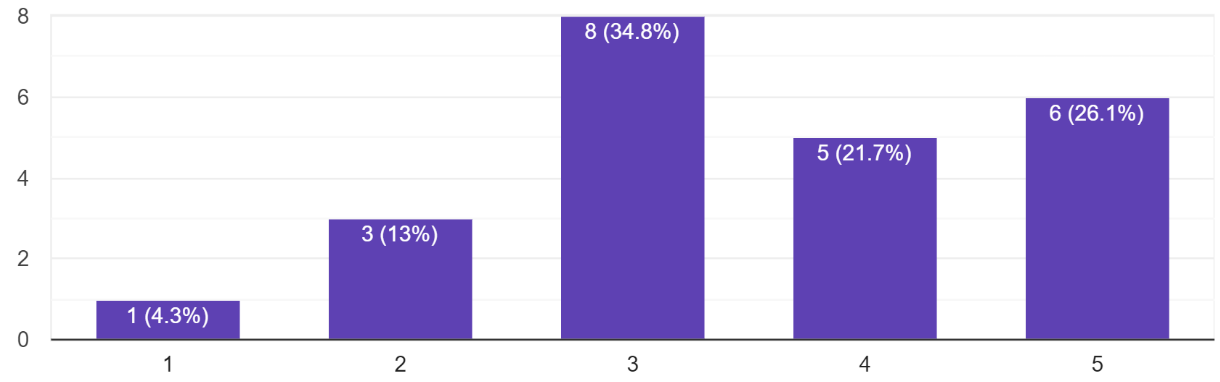

Figure 10C: Ratings from participants based on the brightness of the light source

Question 11:

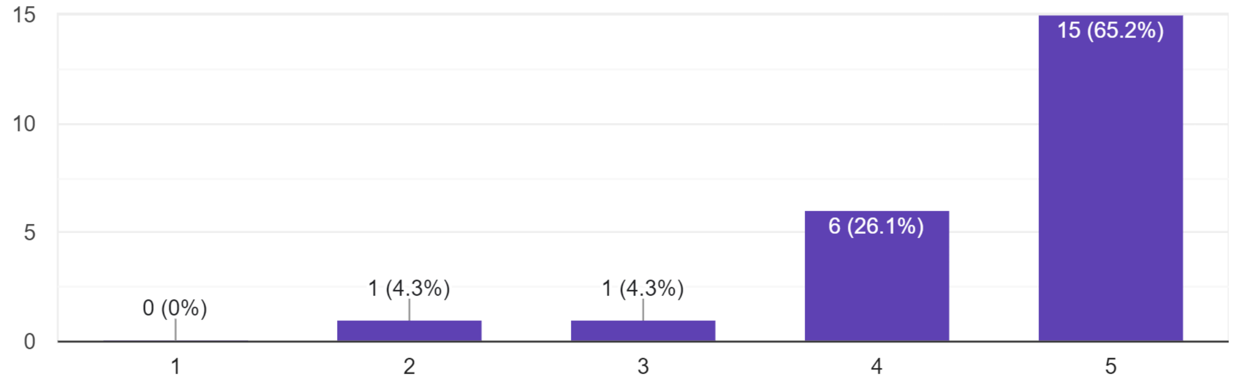

Figure 11C: Ratings from participants based on the comfort of the handle

Question 12:

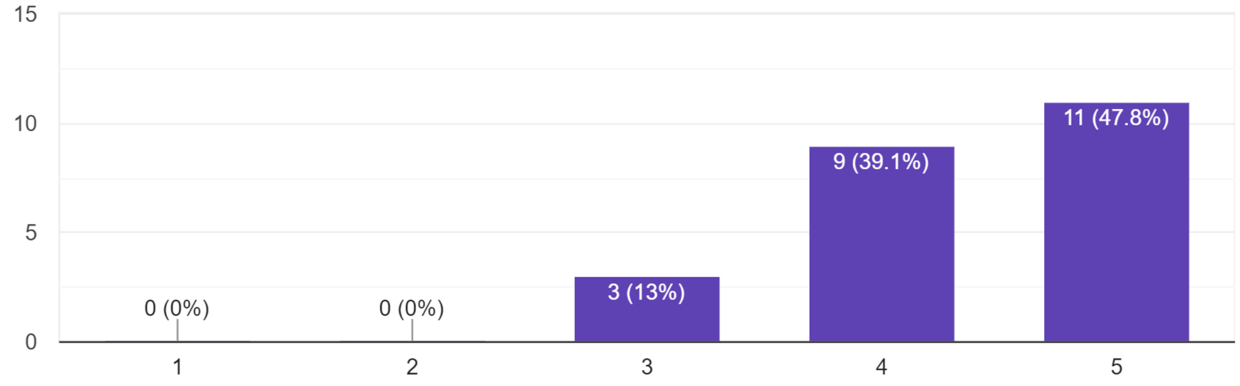

Figure 12C: Ratings from participants based on the size and weight of the device

Question 13:

Answers to the question: What noticeable drawbacks were there with the dual device in comparison to the video otoscope?

- Loose otoscope cone
- Poorer resolution and lighting
- Screen for visualization was smaller and the light source was more finicky
- The lighting was not as bright as our video otoscope. Overall, this model was easy to use and was very similar to using a handheld otoscope
- Focusing
- Limited range of focus through the lens
- The handle was a little scratchy, and it was kind of heavy
- n/a

Question 14:

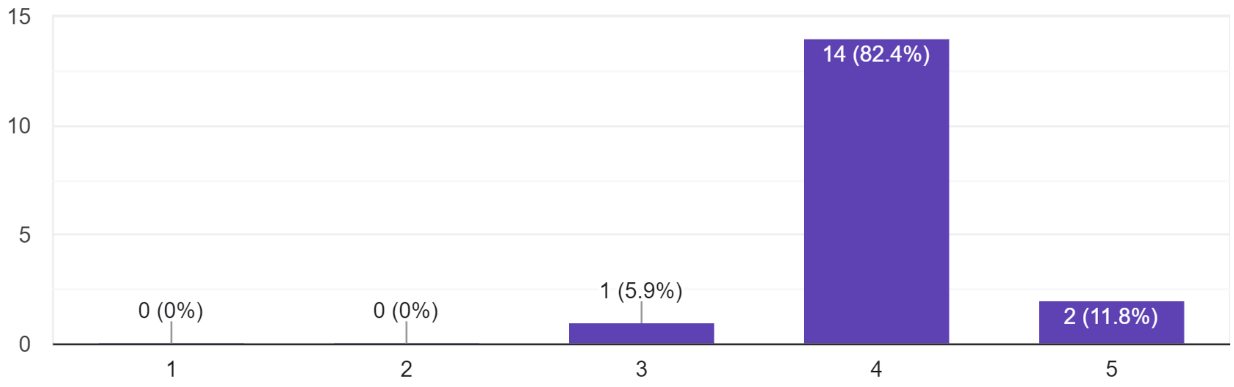

Figure 13C: Overall rating of the prototype otoscope from participants

Question 15:

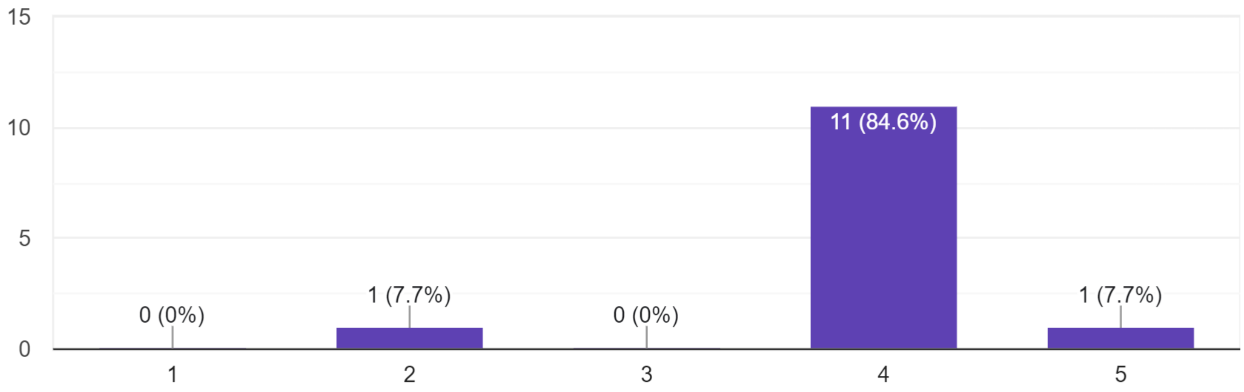

Figure 14C: Overall rating of the current market otoscope from participants

Question 16:

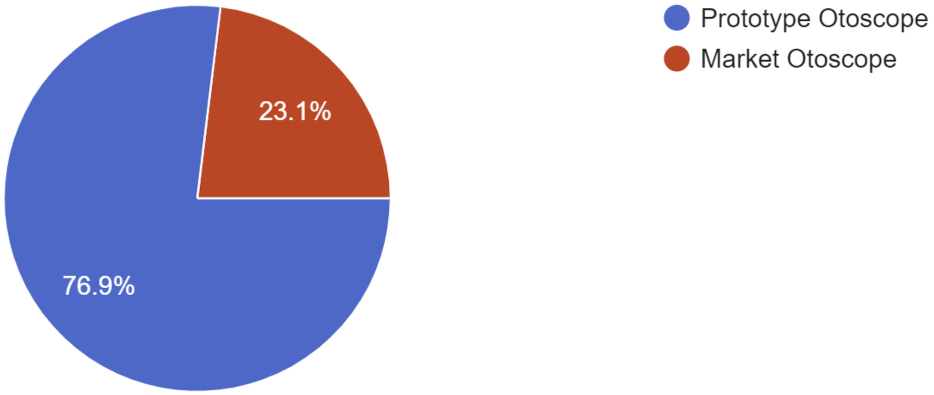

Figure 15C: Percentage of participants who prefer the current market otoscope versus prototype otoscope

Question 17:

Answers to the question: What aspects with the device did you struggle with?

- The cord was cumbersome, the image was blurry until I was basically on top of the image
- Getting it focused when looking through the computer
- Didn't focus fast enough
- You have to locate what your reading through the lens which is a little hard
- Aiming the device at the numbers
- My shaky hand
- Image on screen is too small
- Lighting, resolution
- Having what I see through the lens shown at the same brightness on the monitor
- At first finding the shape, but that might be my lack of experience using an otoscope due to still being a student
- The light source focusing on the heart in the ear canal
- The lighting
- Focus
- Finding the image; poor ability to focus through the otoscope, great clarity on screen
- Getting it to focus, brightness
- The hinge seems a little brittle as if I messed with it a little bit it could break off. The connection from the otoscope lens to the head is loose. I had to refasten it before I used the otoscope
- Camera focus

Question 18:

Answers to the question: Are there any adjustments that you recommend?

- Higher focal length lens
- Make it maybe a little easier to focus in on things
- Focus faster
- You have to cover the top when looking at the device on the screen
- No
- No
- Affix cone more solidly to handle. Make Screen image larger (zoom)
- Increase lighting and improve focus/resolution if possible
- Stronger light source and magnifying the screen
- Brighter and bigger image on the screen
- Brighter light source, increased magnification on-screen
- If the camera quality is routinely superior to image quality through the lens itself, consider using a camera as the main imaging source for both parts of the exam rather than allowing the naked eye to be in charge of one part, such as by placing the camera feedback within the otoscope as well as via USB.
- Brighter lighting
- The adjustments are the struggles
- Handle less scratchy
- Cut out all that black space around the video. Plus that could magnify it so it would be easier to see on the screen so I'm not straining my eyes
- Make wireless

Question 19:

Answers to the statement: Additional Comments.

- Awesome!
- Great job! Super impressive
- N/A
- Super cool. I love the shape. Reminds me of a Smurf
- Nice
- Great Product!

Appendix D: Supplementary Designs Models

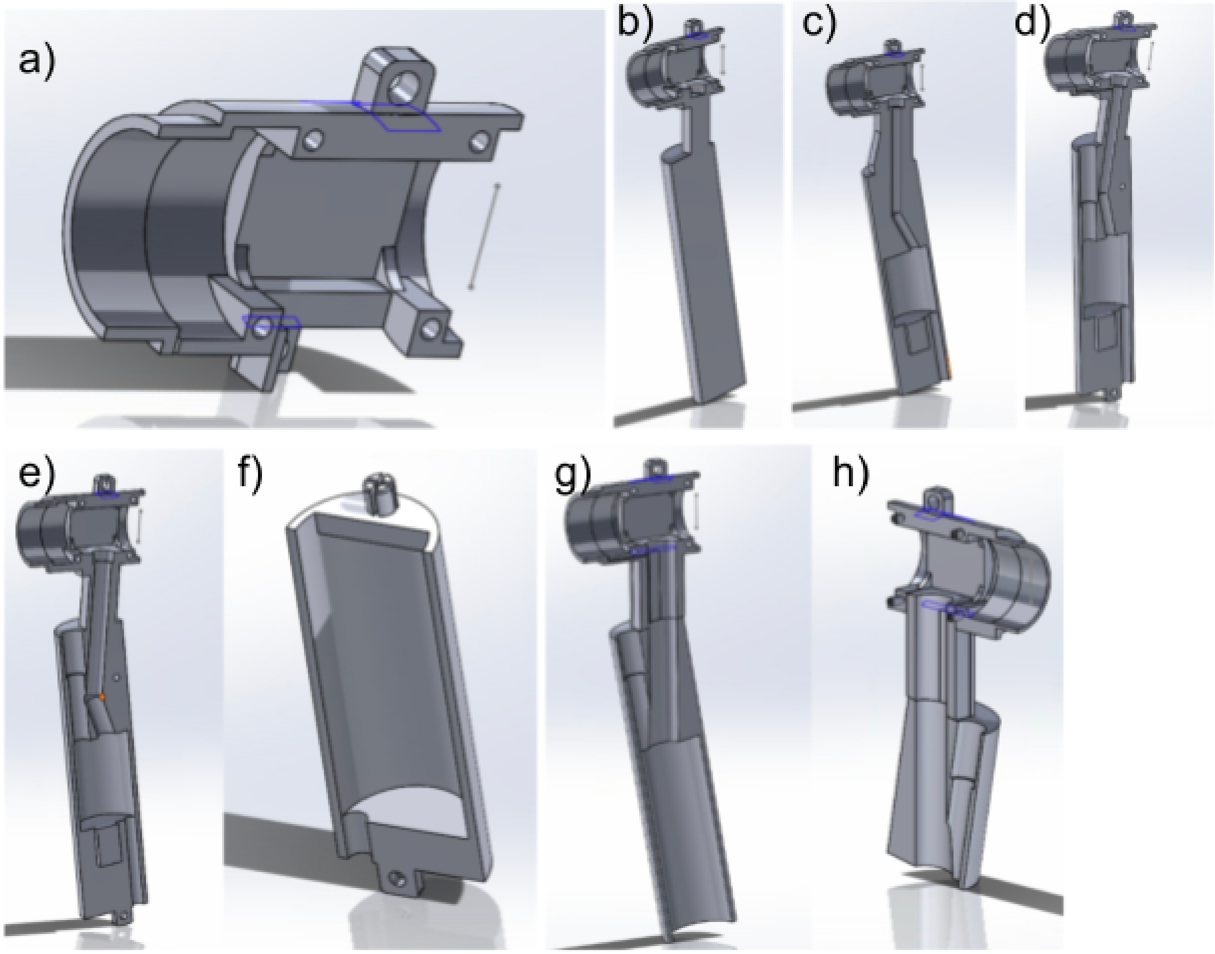

Figure a) Original Otoscope Head Design. b) Otoscope head with otoscope handle. c) Otoscope body with 5.5mm camera track and battery holder. d) Otoscope body with button track e) Otoscope body for 12.5mm camera. f) Battery case initial design. g) Otoscope body alternate design with extra spacing and curve avoided in camera track. h) InitialSymmetrical Cover.

Appendix E: Expense Chart

Total budget: $5000

Item Name	Vendor/ Part Number	Manufacturer	Cost	Quantity
One Way Mirror Privacy Film	Amazon B0BXL38743	FILMGOD	$18.98	1
Beam Splitter Cube 50R/50T 20mm	Amazon B0B34FK2GF	NYJLGD	$21.99	1
Digital Otoscope	Amazon B0C4KYGBQW	Anykit	$36.98	1
Endoscope Camera	Amazon B07PBF6DX5	T-Takmly	$37.86*	1
Endoscope Camera	Amazon B07HVT2XZL	Teslong	$49.99	1
CR 2032 Lithium Batteries	Amazon B071D4DKTZ	LiCB	*See note at the end of the table	1
Micro Litz White LED	Amazon B091BS2ZLW	keenus	*See note at the end of the table	1

CR2043 Battery Holder	Amazon B09KTXB87B	Alinan	*See note at the end of the table	1
Lens 25D100FL	Edmund 32-481	Edmund	$28.50	1
Lens 25D100FL	Edmund 32-481	Edmund	$45.50	1
Beam Splitter Plate 20x27mm 40R/60T	Edmund 46-694	Edmund	$48	1
3D print/Hardware	MakerSpace	N/A	$25.73	N/A

*Ordered together with Camera with a total price of $37.86

Appendix F: Detailed Materials Rationale

Endoscope Camera: The two endoscope cameras under consideration are the: T-Takmly endoscope (TE1) and Teslong auto-focus endoscope (TE2). Both endoscopes are designed with semi-rigid camera cords. TE1 has a narrow focal length ranging from 20 mm to 100 mm and a lower resolution of 1280x720. TE2 has a far better desired focal length ranging from 17 mm to 30,000 mm and can auto-focus with a maximum resolution of 2560x1980. During preliminary testing of both cameras, the team found that TE2 resembles the closest image quality to the 12-megapixel camera used as the team's standards.

Beam Splitter: In comparison using a beam splitter plate or a beam splitter cube, the team evaluated both and decided to move on with the cube. The reason is that a cube fits better within the otoscope head and is thus less likely to shake. A cube shape is stiff and takes up more space within the otoscope which seems less likely to work, however, to fit the plate, intensive CAD modification is needed thus less desire. Also due to the thin nature of the plate, the team considered that a plate has a higher potential for damage during the fabrication and assembling process. Further mechanisms and camera specifications can help determine the best ratio, however, the endoscope camera as mentioned earlier is manufactured and is beyond the scope of this project to disassemble and do further experimentation.