The 3D Printing of a Microscope: Individual Contribution

University *of* Glasgow: 2325410

1. Introduction

An optical microscope is effectively a system of lenses used to magnify very small objects so that they are visible to the naked eye. Typical laboratory optical microscopes have magnifications within the region of 40x to 100x. Figure 1.1 shows the generic design for an optical microscope.

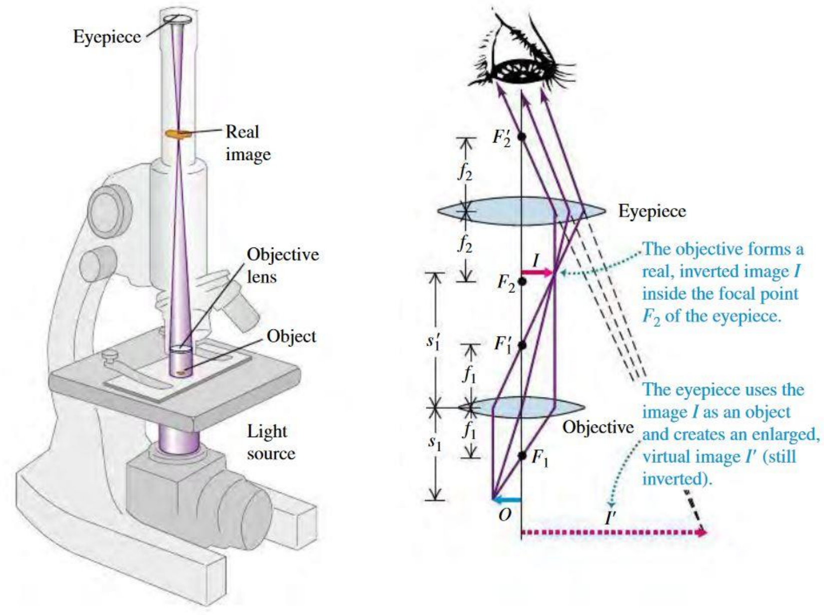

Figure 1.1: Generic Design for Optical Microscopes

Light is incident on a sample and passed through an objective lens and subsequent tube lens to the eyepiece. The product of the magnifications of the tube and objective lenses result in the total magnification of the device. Most optical microscopes fit for laboratories are very costly and require maintenance in order to be fit for research purposes. In addition to being costly, laboratory microscopes have varying objective lenses to produce different magnifications and allow for coarse and fine adjustments of the sample location.

The design team was tasked with the creation and 3D printing of a cost effective optical microscope which could be controlled via an Arduino and LabView interface. I opted to focus more on the modelling aspect within the design team. This involved translating many of the features that are associated with a typical optical microscope into a 3D printable format. The design also had to be free standing and rely very little on pre-existing components such as those from ThorLabs.

In order to model the parts Autodesk Inventor was used as it was the most familiar program to the design team. Models were created within Autodesk Inventor, assembled together within the software in order to minimise part failure and inconsistency and finally converted to .STL files. Stereolithographic files or .STL files were used as the standard export format as it simplifies the workload on the slicing software used. Finally, to convert the created models to .GCODE files, the files which interface with the 3D printers, Cura was used as it was the most reliable and cooperated well with the Ultimaker brand 3D printers available.

2. Preliminary sketches and design iterations

The initial design for the microscope revolved around a system on guide rails. Components would be modelled and then, one by one, slid onto the track and clamped in place. To gauge the overall footprint for the design, a tube lens holder, courtesy of ThorLabs, was slid onto four cylindrical standoffs, standing upright, arranged into a square and clamped in place. Figure 2.1 shows the initial sketches for the railed design.

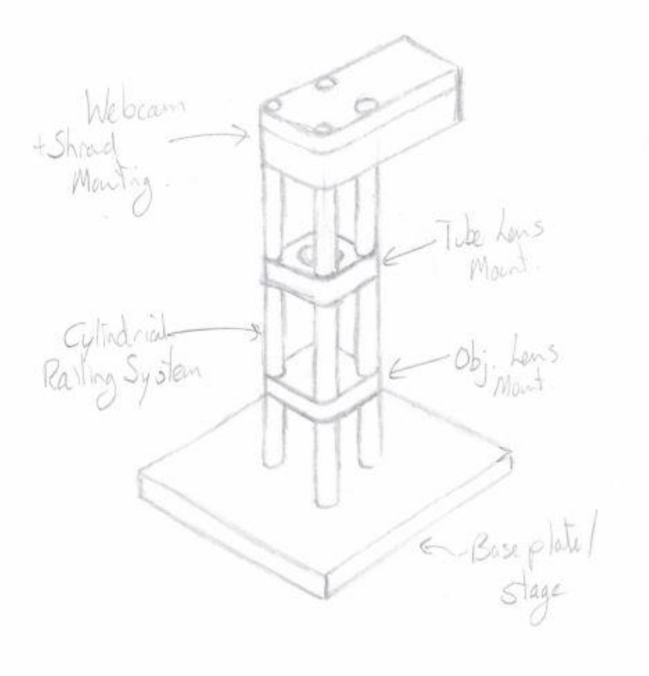

Figure 2.1: Initial Rail Design

This design makes it relatively easy to ensure every component is aligned with one another. It is completely modular in a sense that all components may be swapped out for new ones with ease. The main disadvantage of this design is that it is very inaccurate. Mounts have to be slid on and clamped into place meaning there is no feasible way for extremely fine adjustments. Additionally, the design relied heavily on pre-existing parts from ThorLabs, resulting in a microscope that was not a standalone product. This design was then later revised in favour of a more static design with minimal moving parts and room for fine and course adjustments of the objective lens.

The overall design incorporates the use of a webcam and as such it was the job of the design team to model a mounting system for the device. Using a set of callipers, a colleague measured the dimensions of the webcam circuit board and location of the mounting holes. From the measurements taken a pictorial sketch of the mounting system was constructed. Figure 2.2 shows the pictorial rendering produced from the measurements obtained.

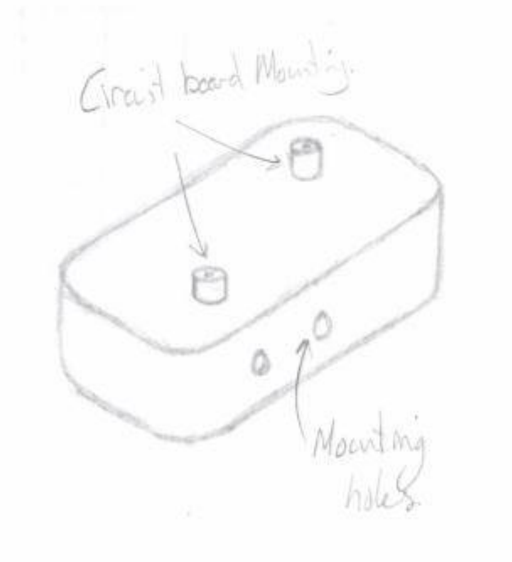

Figure 2.2: Initial Webcam Mount Design

This design considers the fact that the back of the circuit board is not flat hence the raised sections for screws. Four holes were also included for use in the railed system design however this feature did not make it to the final design. This initial design did not consider the possibility of adding a shroud to limit the light reaching the aperture. Later in the progression of the model, mounting holes were added to the backside of the design and mounting holes for a shroud were incorporated. A shroud was fashioned to fit over the cavity for the circuit board with a hole present at the aperture to allow light to enter.

A condenser also had to be constructed in order to eliminate the grid pattern created by the L.E.D. used. After examination of the plano-convex lenses provided, the design team produced a sketch of the condenser design which would incorporate both these lenses, the L.E.D and an optical cable. Figure 2.3 shows the initial sketch of the L.E.D. condenser design.

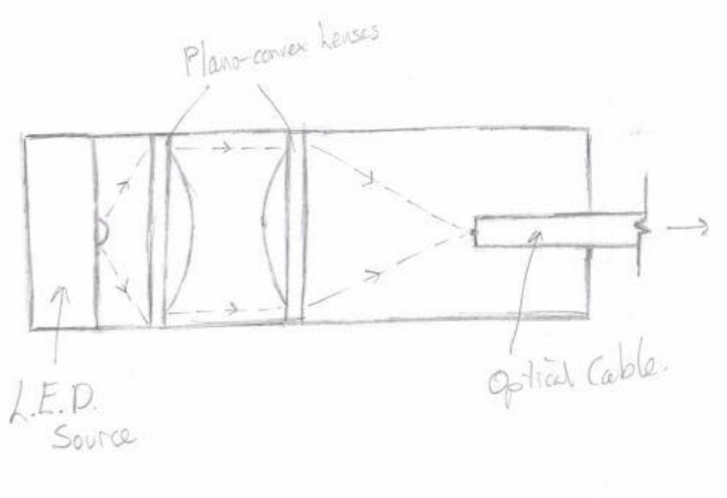

Figure 2.3: Initial L.E.D. light Condenser Design

It can be seen from the above, light originates at the L.E.D, passes through the system of lenses and exits through an optical cable. This design features a ribbed interior which allows the manipulation of the plano-convex lenses. It also includes a moveable cone with a cylindrical cut out for use with the optical cable. This allows the user to move the cone to the focal point created by the last plano-convex lens in the system, collecting the vast majority of the light from the L.E.D whilst removing the grid pattern. Subsequent alterations of the condenser would shorten the length of the condenser, widen the ribbed cavities and refine the design of the moveable cone.

In order to integrate the design with the progress of the electronic team a motorised objective lens holder was proposed. This would function using one stepper motor turning a threaded shaft into or out of a threaded nut attached to the objective lens mount. The initial proposal can be seen in figure 2.4 taking inspiration from most linear track systems.

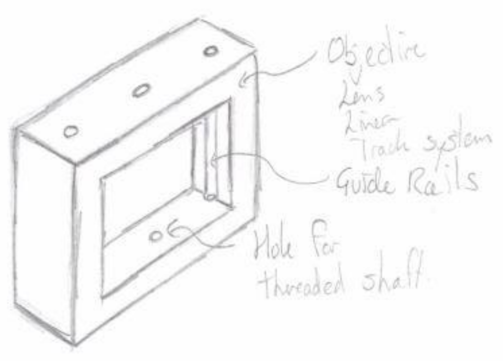

Figure 2.4: Initial Motorised Objective Lens Design

In order to move the objective lens up and down a threaded rod may be driven into a hexagonal nut sunken into the base of the objective lens mount. This base then would slide on two rods at either side of the device, reminiscent of a linear track system, in order to guide the direction of travel. This turned out to be the most altered design of all the assemblies in the entire project. Immediately following this proposal, mounting screw holes were added to the back of the device as well as impressions for the guiding rods to be fixed to. Further to this addition, a mounting system for the stepper motor was incorporated as well as integration between the stepper motor shaft and threaded shaft. The thickness of the design was lessened to decrease printing times. Following this, the objective lens mount was subdivided into two sections, a section that interfaced with the threaded rod and a section which interfaced with the lens. This allows for the hot swapping of objective lenses in the event of part failure or to receive a better magnification. Future design iterations could incorporate a quick release magnetic system for ease of swapping lenses.

The final section of the microscope to be designed was the stage and subsequent stage condenser. After the examination of how the light would behave when it originates from the optical cable a second condenser was required to refocus the light back to a single point. This indicated to the design team that the second condenser unit and stage had to be linked or very close to one another. An initial sketch for the design of the second condenser and conjoining stage may be seen in figure 2.5.

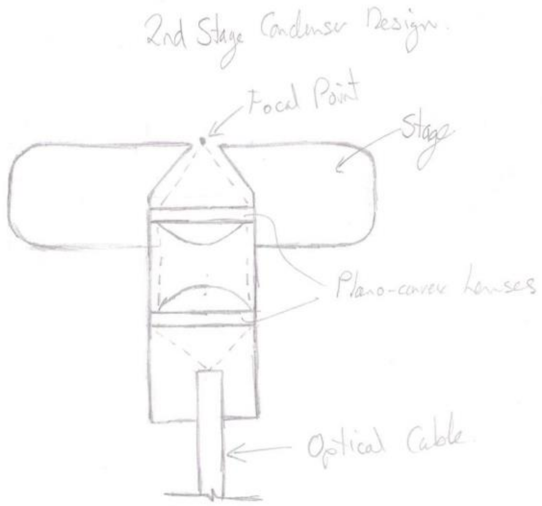

Figure 2.5: Original secondary condenser and stage design

This design revolves around countersinking the condenser partially into the stage design. This ensures that the distance between the lens exit of the condenser and the stage is the focal length of the lens used. Further iterations of this design include the removal of the lens slide holder and removal of the stage altogether in favour of slide mounting brackets.

Throughout the course of the design process it was suggested that the microscope could be placed horizontally instead of vertically as a design variation. This design iteration may be seen in figure 2.6 which illustrates both a vertical assembly and horizontal assembly.

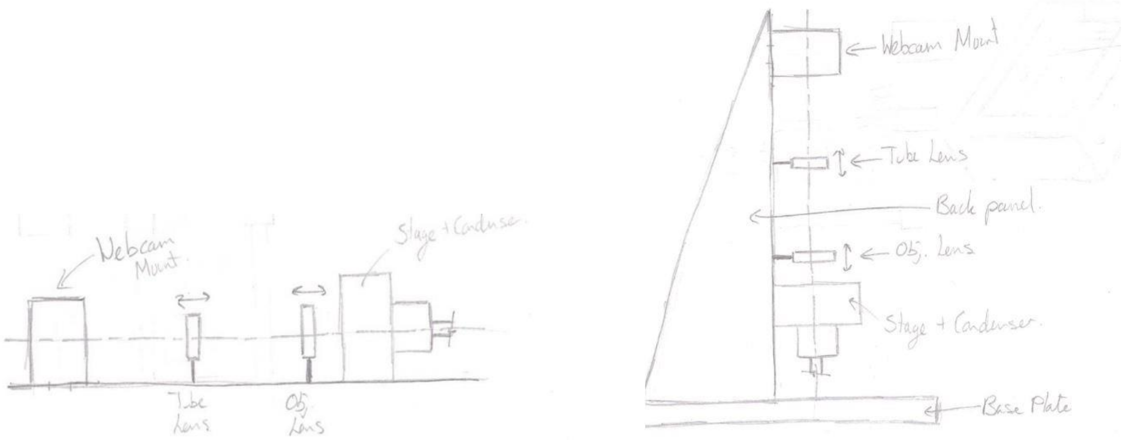

Figure 2.6: Proposed Horizontal (Left) and Vertical (Right) mounting options

Similar to previous projects, the design could be mounted horizontally and utilise the same base as the previously printed optical experiments saving materials. To mount the assembly vertically would require a back panel and two side panels cut increasing the time taken to complete the model. The advantage of the vertical design is that the slides examined would not have to be fixed in place to prevent them from sliding. With the use of the laser cutter permitted the design team opted for the vertical mounting approach leading to a complete standalone product.

3. Production of Parts and assembly

To begin modelling, a base module was constructed from the .STL file downloaded via ThorLabs of a tube lens holder. This module was used to create the final design for the top section of the apparatus consisting of; the tube lens holder, webcam mount and webcam shroud. The most simplistic part to model was the tube lens holder. Figure 3.1 shows the final rendered design of the tube lens holder.

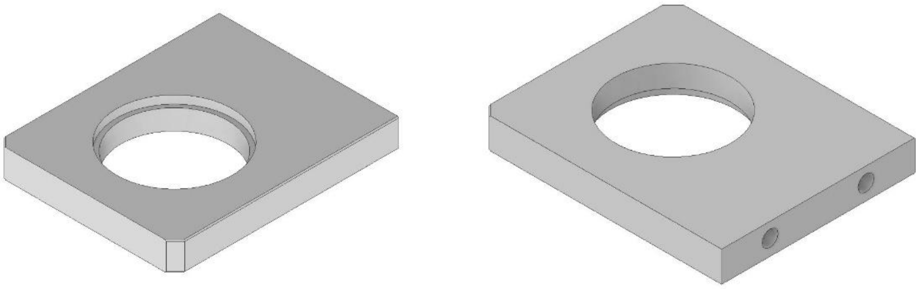

Figure 3.1: Finalised tube lens holster front isometric (left) and back isometric renderings (right)

It can be seen from the above that mounting holes have been supplied to the back of the object for mounting with a Perspex back panel. A circular cut out has been constructed with a view to keeping the lens flush with the surface of the holder. This design allows the lens to be swapped out and easily cleaned if necessary.

After modelling the tube lens holder, work began on modelling the webcam mounting system a subsequent shielding device. The main motivation for having a separable mount and shroud system was to allow quick access to the webcam circuit board itself in the event of a board fault. The shroud could also be removed entirely in favour of other alternative light blocking techniques. The design for the shroud and webcam mounts may be seen in figure 3.2.

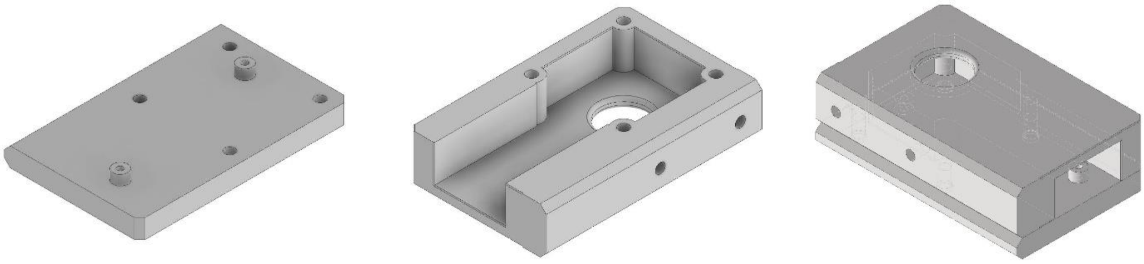

Figure 3.2: Finalised webcam mount (left), webcam shroud (middle) and the final assembly of the two parts (right)

Illustrated in the above is the assembly of both the shroud and mounting system. On the mount itself there is raised sections for the circuit board screws, accounting for the nature of the circuit board. The shroud has a circular cut away in order to allow light from the object to pass to the aperture. The shroud also has a rectangular cut out for cable managing the wires protruding from the circuit board once installed. The chamfers near the mounting holes were applied in order to reduce the material warping when undergoing printing. The mounting edge must remain flat in order to ensure the de vice is flush with the back panel.

The central section of the microscope consists of; the motor mounting system, objective lens mounts, stage and secondary condenser. This system relies on one stepper motor reducing the risk of mechanical failure. In order to provide an accurate representation of the final product a model for the stepper motor was sourced online. The finalised central section may be seen in figure 3.3.

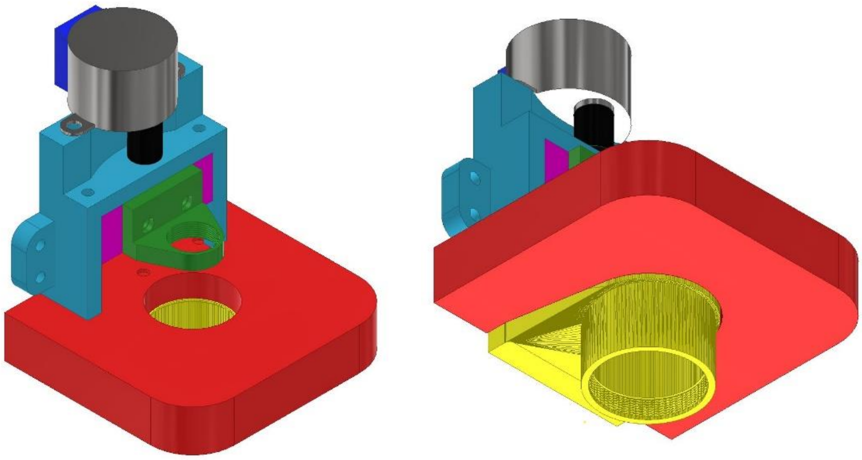

Figure 3.3: Finalised assembly of the secondary condenser, stage and motorised objective lens platform

A possible improvement on this design would be to remove the screw attachment mechanism for the objective lens holder and instead use magnets. This would allow for the objective lenses to be hot swappable, a feature most modern laboratory microscopes have. To minimise material used and printing times the infill for the stage was decreased to 5%. Mounting holes were also incorporated onto the back of the stage and condenser unit. This design requires two cylindrical metal shafts 20mm tall and 3mm in diameter to act as guide rails for the motion of the objective lens holder. In addition to this, a threaded shaft 20mm tall along with a hexagonal threaded nut must also be used to move the objective lens mount with the stepper motor.

The final section, the lower section consisted of only the L.E.D. condenser. This had very few alterations to progress to the final design. The resulting design allows the user to adjust the locations of the plano-convex lenses. Figure 3.4 shows the completed assembly of the L.E.D. condenser unit as well as an elevation view for clearance purposes.

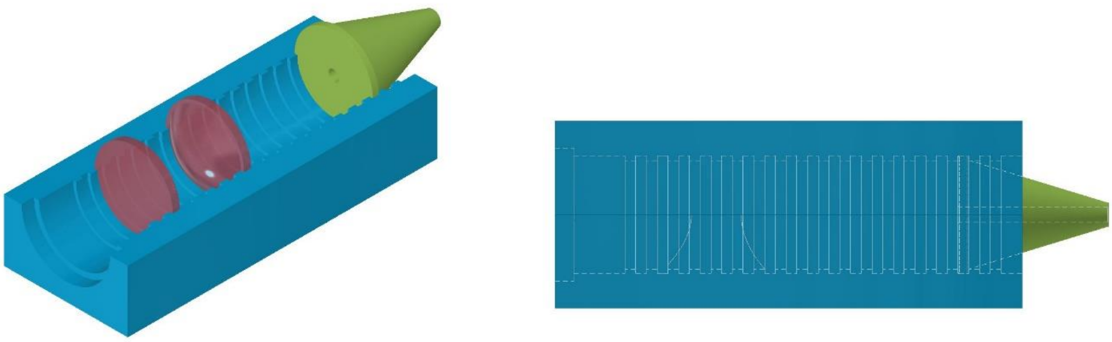

Figure 3.4: Finalised primary condenser rendered with plano-convex lenses

The ribbed design of the inside of the condenser allows the user to adjust locations of internal components such as the optical cable mount and lenses. In this design the L.E.D would be located to the far left and light would exit to the right. The optical cable mount initially was completely hollow but this was changed because the cable would not lie at the focal point. Alterations to this design would include shortening the length of the chamber and removal of redundant ribbed sections to decrease printing time. The optical cable mount may also be integrated into the bottom half, keeping it a solid part.

With all sections modelled and functioning as desired a final assembly was constructed to create a drawing for the back panel. This drawing would then be exported as a .DXF file for the laser cutting of a Perspex sheet. The final assembly may be seen in figure 3.5 which illustrates the back panel, top and middle sections of the design and shows the final design achieved complete with side panels and a base plate.

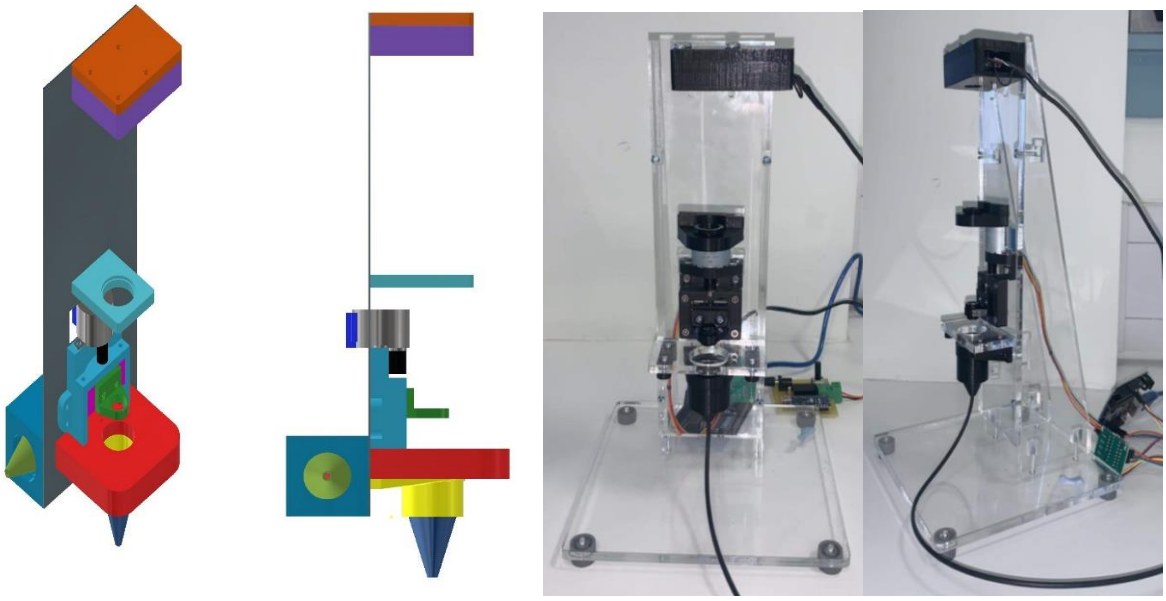

Figure 3.5: Final assemblies within software (left) and finalised product complete (right)

Due to the design of the condenser the location of the condenser may be altered to fit anywhere on the model. An optical cable would also be present connecting the condenser to the second stage condenser. This was the final design modelled on Inventor and was subsequently altered slightly on OpenSCAD to achieve the final printed result.

4. Conclusion

In summary I successfully modelled and produced the component parts to create a fully functioning microscope. This microscope was able to successfully image items such as pollen, pine stems and ear wax. The design remained relatively simplistic yet highly functional and managed to incorporate the key features of most modern day laboratory microscopes. Most importantly the design is relatively cheap to replicate, requiring only purchase of the stepper motor and Arduino components. Additionally, the design of each piece allows each part to be C.N.C machined separately, effectively increasingly the longevity of the device. In terms of future projects, this microscope may be of use in such fields as biology or may be improved upon and expanded to include additional hot swappable objective lenses.