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The University of Tennessee at Chattanooga

University Honors Thesis

Examining the Intersections of Art and Science through Photomicrography

Lauren Solomon

Directors: Prof. Andrew O'Brien and Dr. Ethan Carver

July 2022

Introduction

The aim of this thesis is to examine the intersections of art and science within the realm of microscopic photography, also known as photomicrography. At the beginning of this project, photomicrography was an entirely new field to me, and the joys and challenges of attempting something unfamiliar enabled my wonder in discovery. As a student pursuing a BS in General Biology, science is an omnipresent aspect of my life. As a third-generation photographer, art through imagery is as much a part of my identity as science. This interdisciplinary concept of photomicrography is the basis of this thesis– to pursue science and art simultaneously. Doing so opened my eyes to a different kind of research–a process that was driven by the exploration of a familiar scientific tool as a new creative medium. To properly use photomicrography as a tool for both scientific and creative inquiry, we must first understand its history and relevance to humanity.

In 1590, the first compound microscope became known within the scientific community through the passing of letters and its appearance at high-class parties. While it struck awe in the viewers, it was considered more like a toy than a device for radical scientific discovery. While the identity of the inventor is somewhat questioned, the discovery is generally credited to Hans Janssen, a Dutch lens-maker. Many versions of the compound microscope were developed, nearly seventy years went by before any "systematic work of great and lasting scientific value" was completed (Ball). In 1661 Marcello Malpighi, an Italian anatomist, published *De Pulmonibus Observationes Anatomicae.* This detailed a study in which he examined the dried lung of a frog under a microscope enabling his discovery of capillaries. According to author Clara Sue Ball from the University of Oklahoma, Malpighi's "use of [the microscope] was truly scientific because it was systematic and was done in an attempt to find the explanation of a problem in science which had existed [before him]" (Ball).

The most well-known individual to use the microscope for scientific purposes following Malpighi was Antonie Van Leeuwenhoek. Around the 1670's Leeuwenhoek, a Dutch lens maker crafted his own lens that could view up to 300x magnification. This advance in technology was significant, as the previous microscopes only allowed for a

magnification of 20 to 30x life-size. In a biography about the Dutch scientist, Encyclopedia Britannica reports that “although Leeuwenhoek’s studies lacked the organization of formal scientific research, his powers of careful observation enabled him to make discoveries of fundamental importance.” Leeuwenhoek has been credited with the discovery of bacteria, protists, nematodes, and spermatozoa, among other things (Wills).

Although Leeuwenhoek has been referred to as the Father of Microbiology, the field was not established as a distinct science until the 1850s. This paralleled Louis Pasteur's hypothesis of microorganisms being responsible for the fermentation of fluids (Opal). “Pasteur’s work showed that fermentation, spoiling, or contamination of organic substances was due to the presence of environmental microorganisms” (Opal). Robert Koch, a German Physician, then created a set methodology known as Koch’s Postulates which could establish a cause and effect between microorganisms and disease. The combined efforts of Pasteur, Koch, and other scientists, provided evidence for the germ theory of disease and launched the field of microbiology and its many subsets.

Briefly, before the significant recognition of microbiology as a science, was the developing art of photomicrography. Henry Fox Talbot was the first to create photomicrographs using a solar microscope around 1837. While his micrographs were all at magnifications lower than 20x, it was still a historic accomplishment (Overney). Over the next century were astonishing technological advancements in the world of photomicrography, with new equipment models coming out nearly every decade. The advancements in microscopy within a single company demonstrate the rapid growth within the field. Leitz Works, for example, started around 1851 and by 1900 they had sold 54,000 of their microscopes. Leitz introduced its “flagship microscope system, the Leitz Ortholux” in 1937 (Overney). In the following decades photomicrography quickly caught up to the sophistication of film emulsions. In the 1960’s Leitz released the Orthoplan Microscope and Orthomat Camera, which was recognized as “one of the best fully automatic microscope cameras for 35mm photomicrography” of its time (Overney). Between 1937 and 1972 Leitz alone released 24 different models, reaching 1,000,000 microscopes sold by 1977 (J.Grehn).

In 1975, camera manufacturer Nikon started a worldwide competition for photographs taken through a microscope. Now celebrating its 46th year Nikon Small World has an extensive gallery of micrographs from 1975 to the present day. Not only does this website (www.nikonsmallworld.com) host the premium work of photomicrographs but it also serves as a virtual timeline for the evolution of photomicrography, technologically, scientifically, and artistically.

> The Nikon Small World Competition first began in 1975 as a means to recognize and applaud the efforts of those involved with photography through the light microscope. Since then, Small World has become a leading showcase for photomicrographs from the widest array of scientific disciplines. (Nikon Small World, n.d.)

During the 20th century, there were other pioneers of combining science and photography. One great example is Berenice Abbott, a photographer who worked to communicate science through her artistic medium. She created images for science textbooks and worked as the photography editor of *Science Illustrated Magazine*. Abbott thought photography was "a realistic medium appropriate to a realistic and scientific age" (Rogers). Her attempts to communicate specific scientific ideas made her stand apart from her fellow photographers. These topics are discussed in an article titled *Making Science Visible: The Photography of Berenice Abbott*. This article was cited as a resource on the work of Berenice Abbott by the *Seeing Science* initiative. Author, Hannah Star Rogers, argues that "artists and image-makers are too often considered to be outside of science" even when their contributions enable scientific progress (Rogers). Projects like *Seeing Science* can work to overcome this misconception. The Seeing Science initiative is a University of Maryland, Baltimore County (UMBC) project whose goal is to explore "the central role photographic images play in defining, shaping, promoting, and furthering science" (http://seeingscience.umbc.edu/about/). This website hosts articles, short essays, quotes, images, and more, all to show the viewer the interconnectivity of science and artistic photography.

Background

Many scientific fields such as Medicine, Geography, Zoology, Botany, Oceanography, Geology, and Biology use microscopy as an important tool. The microscope, along with photomicrography, is a significant resource in research and discovery. Sandra Santos, the author of *Crossing Borders: the Path of Photomicrography towards Artistic Recognition*, explains how microscopy expanded "the spectrum of human vision into the 'invisible' [and] played a fundamental role in the reverence towards science." Through the microscope, humanity was exposed to a whole new world of visual and scientific curiosity.

New aesthetic elements were brought to the public through photomicrography; patterns, colors, curves, and transparencies, all now visible aspects of microscopic life. These patterns and structures influenced the artistic world, and are repeated across artists and styles. They are even recognizable in some of the most famous artworks, such as patterns in The Kiss by Gustav Klimt, which resemble photomicrographs of human tissue as shown in the *Handbook of Photomicrography* (Santos). As stated by Santos, "art and science were brought together even closer than before, in a combination of scientific objectivity and aesthetic inspiration." The cooperation between art and science, particularly in the context of photomicrography produces stunning results that are focused on harnessing new forms of perception.

An aspect of photomicrography not yet addressed in this proposal is the high costs associated with the equipment. In contrast with the scientific community, artists wanting to venture into photomicrography are often faced with a lack of access to high-quality microscopes. This costly equipment is more readily found in well-equipped laboratories within research institutions. This can help us understand why most photomicrographs such as the ones seen in Nikon Small World are attributed to scientists. "Without abandoning the scientific and technical quality, [these] artist-scientists rearranged, colored, highlighted and interpreted the infinitely small as to capture the hidden beauty of the vegetable, mineral and animal realms with a camera" (Santos).

Digital advancements such as the internet, digital photography, and digital media have enabled photomicrography to grow significantly as a field. The invention of the digital

camera, by Kodak in 1975, simplified the lengthy efforts of processing film and printing from negatives. Not only did this invention make photography more accessible to the general public but it also benefited numerous scientific fields. Laboratory scientists could take digital micrographs and see the image within a matter of seconds. In comparison to the processes of film photography, this was revolutionary. Photomicrography for both scientific and artistic exploration benefited from the ease of digital photography. Even such, the author of *Micro Art*, Robert Dabdoub declared photomicrography an art form due to its complexity.

> Photomicrography often requires instruments and techniques not frequently used in traditional photography, and learning how to photograph through a microscope is not an easy task. Many of the procedures, such as lighting, focusing, exposing, and even locating the tiny area to be photographed, are much more complex than in ordinary camera work. (Dabdoub, 2003, p. 7)

A thesis from the University of Colorado, written by Nicholas Eubank, titled *Photomicrography as an Artistic Medium,* further defends the claim that this field can not only be scientific but artistic as well. In this thesis, Eubank explains how photomicrography can connect the fields of science and art to create a truly interdisciplinary endeavor.

> Among the scientists who have begun making art, those who have been the most successful are those individuals who possess an understanding of aesthetics. Scientists who fail to educate themselves about such concepts are greatly handicapped. Similarly, artists who try their hand at science without properly educating themselves are handicapped in the same manner. (Eubank, 2010, p. 26)

Nature and landscapes have been the subject of my photographic style for many years, however following the acquisition of a macro lens my eyes turned to the ground. I began taking close-up shots of patterns and textures I saw in nature. I was captivated by specimens such as moss (Image 1.1), wood (Image 1.2), lichen, mushrooms, and insects. With greater magnification, came a greater curiosity for the small aspects of life. I loved macro because I was able to showcase parts of nature I felt were often overlooked. Some of

my shots are self-explanatory while others take on a more abstract composition. I recognized I could share my love of science and nature through my art. While not everyone would be willing to stop and look at a spider in its web, they might take time inspecting a macro shot and be surprised by the spider's hairy body (Image 1.4). One might find flies to be a nuisance in their life but be intrigued by the many colors on their body or the impressiveness of their eyes. Eventually, through the pursuit of macro photography, I discovered the field of photomicrography and was immediately transfixed.

Image 1.1

Image 1.2

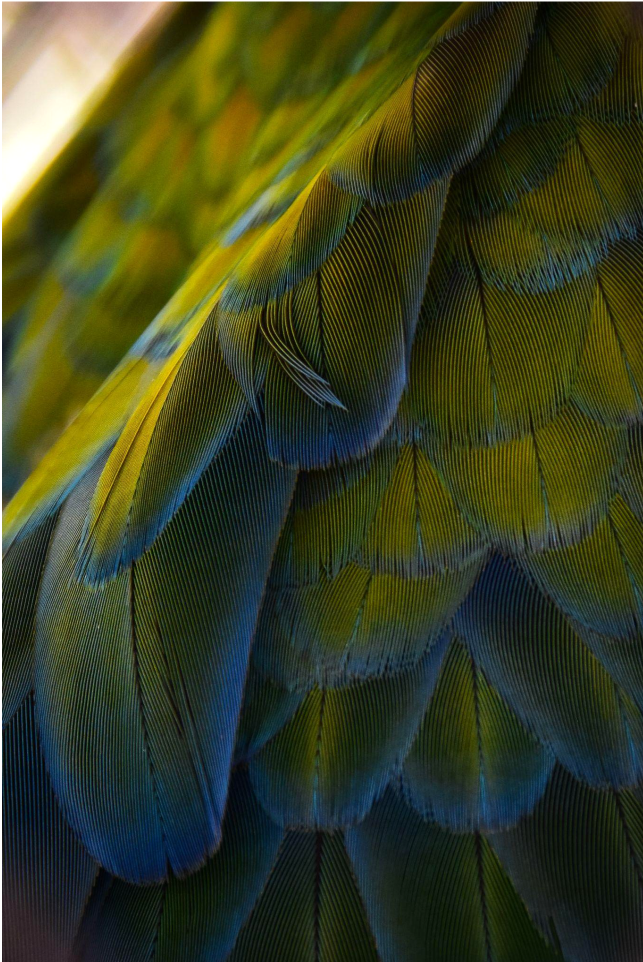


Image 1.3

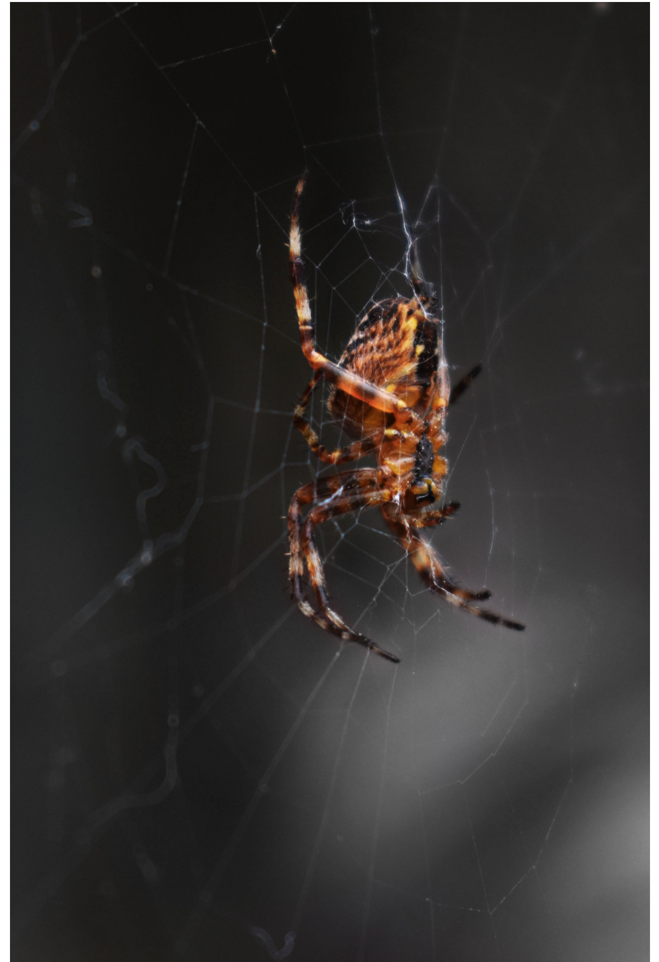


Image 1.4

Objective

Through this thesis, I explored the realm of photomicrography not only as an artist but as a scientist as well. As stated by Santos “scientists and artists, [or artist-scientist] have in their hands the power to be the mediators of the microscopic world. ” I have created a series of micrographs that explored both artistic and scientific pursuits. The overall thesis is both, a body of artistic work and a narrative of my endeavor to understand the science and process behind photomicroscopy.

> [Science] and [art] are working together to create expressive and aesthetically appealing images, portraying the invisible side of the natural world and making it known to the public with the potential of making a difference in how we perceive and appreciate nature. (Santos, 2015, p. 11)

This interdisciplinary topic was brought to life through the use of UTC's advanced microscopes. As mentioned previously, photomicrography is most often done by scientists in well-equipped labs. Thus I partnered with the Department of Biology, Geology, and Environmental Science. After many conversations, I found Dr. Ethan Carver, Professor of Biology and Associate Dean of the UTC Graduate School. He agreed to train me on the microscopes available at UTC. Dr. Carver has a Ph.D. in Biomedical Science and has taught many courses involving the microscopic world.

The main categories of microscopes are light, electron, and scanning probe microscopes. Within the light microscope category are many subsets. The main qualification is that they use light to visualize images. This subset includes brightfield, darkfield, phase-contrast, differential interference contrast (DIC), fluorescence, confocal scanning laser, and two-photon microscopes. Each of these can have particular usefulness when it comes to microbiological diagnostics and research. These light microscopes can also have complementary effects when used together. (*Instruments of Microscopy)*

The next category is the electron microscope. There are only two main subsets in this category, the transmission electron microscope also TEM and the scanning electron microscope, SEM. While both utilize an electron beam to create the image, one visualizes surfaces while the other passes through the object to illuminate thin specimens or cross-sections. The last category I am covering here is the scanning probe microscopes. Within this category are the scanning tunneling microscope, STM, and the atomic force microscope, AFM. An STM can map the structure of surfaces at the atomic level, while an AFM can be used in numerous ways including observing the atomic level of nonconducting specimens.

After learning about the various microscopes I was most interested in working with an SEM, confocal, brightfield, or darkfield. Within the Microscope Lab in UTC's Holt Hall, there are two powerful machines, a confocal microscope, and an SEM. Both pieces of equipment were purchased over ten years ago. While they are not the most current technology they still offer a look into the microscopic that is not achievable with elementary lab equipment. Both confocal microscopes and SEMs are advanced equipment that requires the proper training before any use.

Methodology

Over the summer months of 2021, I worked with Dr. Ethan Carver to train in the Microscope Lab in UTC's Holt Hall. The two machines in this lab are the Olympus Fluoview FV1000, a confocal microscope, and the Joel NeoScope, an SEM. The Olympus Fluoview has five objective lenses: 4X, 10X, 20X, 40X, and 60X. It has a wide range of capabilities including, light microscopy, epi-fluorescence, and confocality. The SEM, unfortunately, had a series of failures and was unavailable to me for many months. Thus, the Fluoview confocal microscope was my primary focus. Beyond training, a microscope's compatibility with photomicrography is also a limiting factor. Within *Advanced Digital Photomicrography,* an article published by The Quekett Microscopical Club, are numerous expert tips on a successful setup. Not only does this article help inform the reader of the best camera for their desired outcome but also covers topics like attachment converters, programming, and editing software. The author also explains how the addition of a few extra tools can eliminate common amateur errors.

While I planned to attach a Sony DSLR camera to the UTC microscope for this thesis work, I soon realized it was unnecessary. The confocal microscope was equipped with a small Excelis digital camera. This specialized camera is meant for exclusive use with microscopes and does not even have a viewfinder. The camera was already connected to the trinocular mount of the Olympus Fluoview when I first entered the lab. This was the setup I used throughout my thesis.

Most modern digital cameras, including the Excelis, can be connected to a computer via a USB link and controlled directly. A third-party 'remote capture' software, called CaptaVison, was necessary for the camera and computer to properly communicate through the linked cable. This connection allows for a live preview of your image where you can make adjustments all from your computer screen. CaptaVision offers many benefits such as control of basic camera functions, a preview of the image on your screen, and image manipulations such as exposure, color temperature, IOS settings, and more. The CaptaVision interface allowed for the simple setup of a shot and instantaneous downloading of all images.

Image Stacking

While Dr. Carver's training was thorough he also encouraged me to learn on my own through experimentation. Over the semesters I learned that the subject matter that can be viewed with the Olympus Fluoview microscope is somewhat limited. To capture a 3-dimensional object I could only use the 4X or 10X objective lenses within the brightfield or epi-fluorescent functions. However, due to the dimension of the object and the short focal length a series of images must be taken to result in a quality photo. Photos must be captured at various focal lengths and then "stacked" together with a specialized program. Between 5 and 10 original micrographs become one stacked photo with the entire object in focus. This method of capturing and stacking can also be utilized for flat specimens as well.

Image stacking combines multiple images taken at different focal depths or exposures into one high-resolution micrograph. While there are a number of stacking software such as Combine-Z, and Zerene Stacker, the author of *Advanced Digital Photomicrography* prefers Helicon Focus for its easy-to-use interface and reliable results. I found Helicon Focus to be a great software and I used it to make countless stacked images. Image stacking became a very important part of my thesis as it allowed for images with greater depth and resolution. Depending on the specimen's 3-dimensionality it was sometimes necessary to take a large series of photos in the exact same stage position, to produce one clear image. For example, one specimen I used was a collected butterfly wing. Images 3.1 and 3.2 are two out of a series of six that were used to create the final stacked

image (3.3). As you can see in each single image there are areas in and out of focus. Helicon Focus program takes these series of images and stacks them, joining all in-focus areas into one image. Most of my images required image stacking to maximize their detail and resolution.

Image 3.1

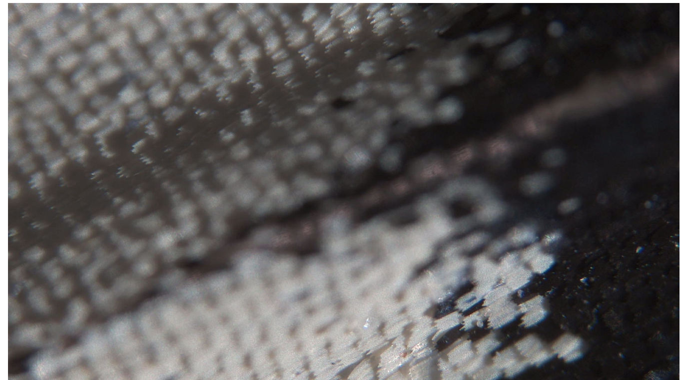


Image 3.2

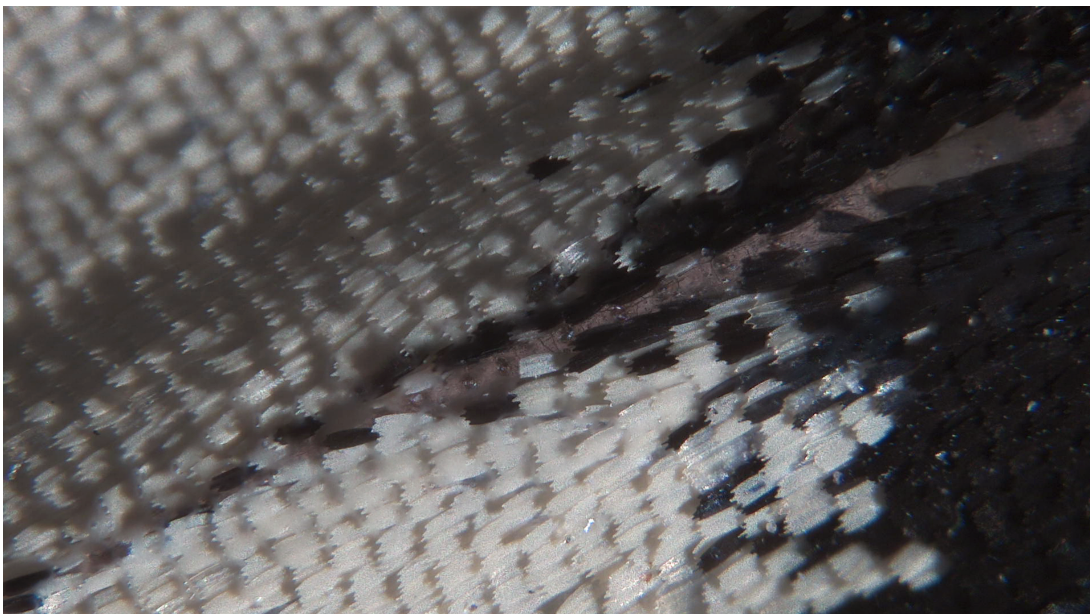


Image 3.3

Lighting

Objective lenses 10X and 20X are good to capture 2-dimensional specimens such as those mounted to a glass slide with or without a coverslip. Although I have learned that in order for these slides to create a good photograph they must either be thin enough to be backlit with the microscope lamp or reactive to epi-fluorescence. Most microscopes offer some internal light source such as a backlight, however, these sources are often fixed and not adjustable. The Olympus Fluoview can be used as a brightfield microscope with illumination from below the slide. A backlight is most useful for prepared slices such as thin cross-sections. This type of illumination is most common in the microscopes used in early education such as middle and high school. However, if the specimen being viewed is not thin enough for light to pass through it, an external light source is necessary.

Light and exposure are important factors in any form of photography, therefore an external light allows for greater manipulation. Nicholas Eubank, a graduate of the University of Colorado, explored many options for external lighting in his thesis *Photomicrography as an Artistic Medium.* Eubank first addressed the financial barrier that he encountered when trying to provide external, independent lights for his photomicrographic work. Through his experimentation, he created a low-cost alternative to high-quality lighting. The base of this alternative includes a simple stand from a hardware store equipped with two alligator clamps. These clamps can be used to attach a variety of small gooseneck lights. The gooseneck feature of these small LED or ultraviolet lights is crucial for the desired mobility. Eubank discovered that "to create the desired lighting solution for a given subject, it was necessary to have a complete range of motion from multiple light sources."

While I planned to use this lighting system, which would only cost between $10 and $20, it was not necessary to acquire my own. Dr. Carver was able to locate two gooseneck lights that were added to the microscope lab for my thesis project. Eubank explains that the approach for lighting microscope subjects should be the same as a portrait model. With adequate adjustability "the lighting [can be] manipulated until it properly capture[s] the character of the subject being photographed" (Eubank). Throughout my work, these

external lights, one on either side, were crucial to the outcome of my photomicrographs. An example of the difference lighting can make is visible in the comparison of images 3.3 and 3.4. These images are both stacks of the same specimen in the same position on the microscope stage. The difference between them is that in 3.4 both gooseneck lamps were being used to illuminate the surface of the butterfly wing. However, in 3.3 only the right lamp was used which created the visible shadows and enhanced the photos depth perception.

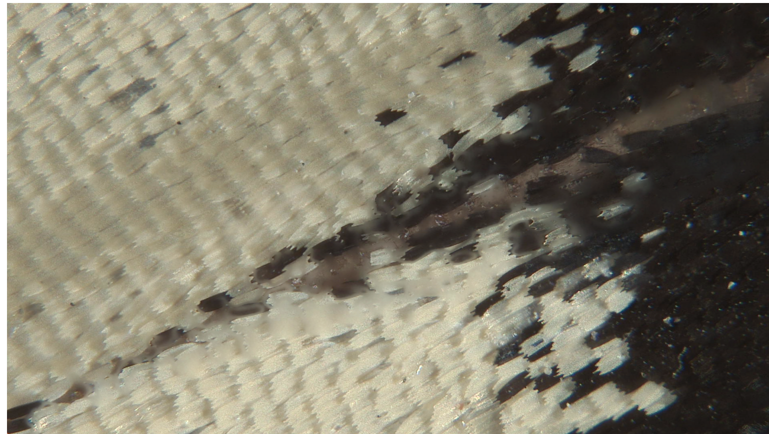


Image 3.4

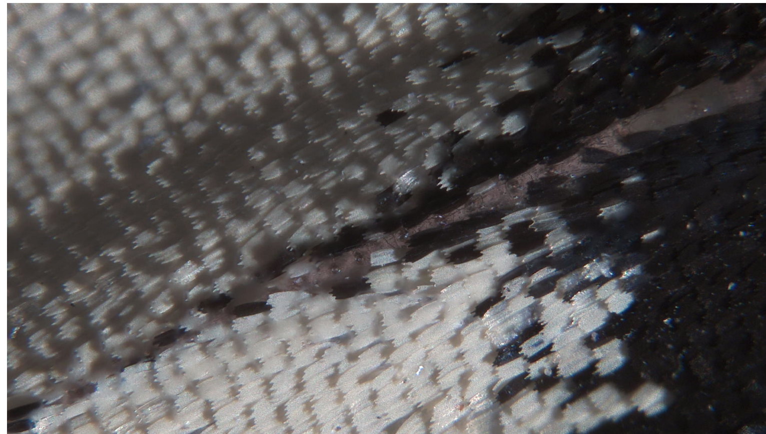


Image 3.3

Light also influences another element of photomicrography. At higher magnifications, the working distance between the objective lens and the slide is significantly smaller. With such a small working distance light refracts and distorts the

image, reducing the resolution. To use the 40X and 60X objective lenses, the slide must go under oil. A layer of immersion oil is added to the coverslip of the slide and the lens is lowered into the oil. This contact layer of oil reduces the refraction of light and allows for specimens to be seen with more clarity. An oil immersion objective lens must get extremely close to the specimens and is therefore restricted to prepared slides with coverslips. Image 4.1 shows the 60X objective lens under oil viewing a slide.

Image 4.1

Editing

Image stacking and illumination are not the only way to enhance a photomicrograph or add an artistic interpretation. The author of the article, *Advanced Digital Photomicrography* offers numerous expert tips on editing programs and useful functions for the photomicrographer. Regardless of the program, the main edits for micrographs are often cropping, color management, exposure adjustments, sharpening, and cloning to remove dust marks (Quekett). While many different editing software are available, Adobe is most accessible to me and was the software I primarily used to make such edits. In addition to the standard edits, there are some functions within Adobe Photoshop that are useful in photomicrography.

The main one is the 'Panorama-Merge'. This function blends adjoining pictures together making one cohesive photo, which is typically used for creating panoramas of a

landscape. However, the Panorama-Merge can also be used to achieve high resolution or to expand the image when the field of view was insufficient for the specimen. I found that the Olympus Fluoview had a very limited field of view, even at the lowest magnification most of my specimens could not be viewed in full. The 'Panorama-Merge' was useful on specimens that were oblong, for example, a cross-section of an onion root tip.

Image 5.1 below, was created by first stacking images of three visible sections, moving from one end to the other. Then the stacked images were run through photoshop's 'panorama-merge' to stitch the full image together. Images 5.2, 5.3, and 5.4 are the three stacked images that 5.1 are comprised of. The power of editing is visible in these examples, not only do the original images not line up exactly but there are excessive amounts of dust spots. Through photoshop I was able to create one cohesive image, remove the dust, and correct the exposure and contrast.

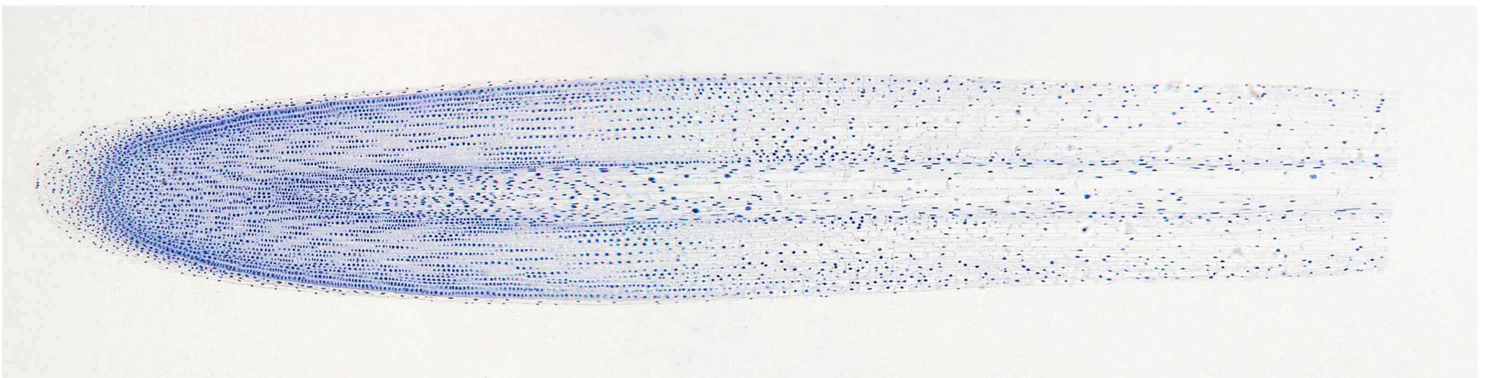
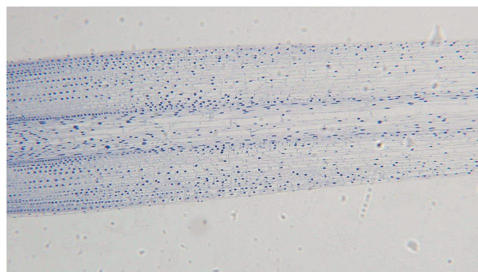


Image 5.1



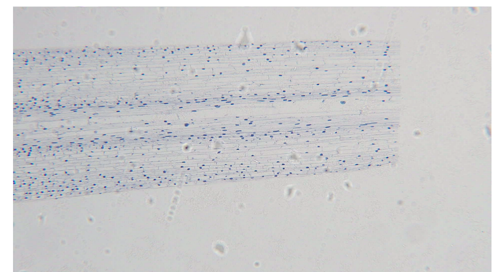


Image 5.2 Image 5.3 Image 5.4

Epi-Fluorescence

Epi-fluorescence is the next capability of the Olympus Fluoview FV1000. Instead of being illuminated with a lamp, epi-fluorescence uses a mercury arc lamp as the light source. The light is reflected down onto the sample rather than from below like in brightfield microscopy. The “desired and specific band of wavelengths” excite the fluorescence molecules or fluorophores in the sample and are then reflected back through the objective lens and past a filter (Spring). Fluorescent microscopy is advantageous to researchers because it can be used to detect and visualize multiple fluorescent molecules by adjusting the excitation and emission filters. This produces distinct channels or light paths. The Olympus Fluoview has three channels, DAPI, GFP, and TRITC. Epi-fluorescence is particularly useful for imaging thicker samples (Spring). If a specimen does not possess natural fluorescence, a dye or stain can be used to detect cellular structures. One of the most commonly used stains is DAPI which binds to DNA. This stain can help visualize the nuclei in a cell. Epi-fluorescence is used in many scientific labs to highlight selective components of a specimen while darkening others.

Within the Microscope Lab at UTC, there were some already prepared slides. Most of them are attributed to Dr. Carver’s Embryology course and students. These slides were of zebrafish embryos at varying points in development. The embryos had been treated with a DAPI stain and could be used for both epi-fluorescence and confocality. There was a DAPI mounting medium that was available for use in creating my own slides. I prepared a number of slides with various subject matters. I mounted more dimensional objects with glue dots and thinner specimens with fluid and coverslips. However, I quickly learned that my slide preparation abilities were on a very amateur level. For example, I sometimes had air bubbles trapped underneath my coverslip. Additionally, I noticed that some of my fluid-mounted slides would dry out over time. This was likely due to air bubbles or an improper seal around the edge of the coverslip. Creating thin sections that can isolate individual cell layers requires a machine and a time-consuming process. The production of thin section slides is certainly a skill gained over time. Unfortunately, within my thesis, I did not have time to also master this skill. Thus, I ordered a few sets of well-made cross-sections from MicroscopeWorld.com.

The following images are of the same zebrafish embryo under all available types of light. To showcase the differences between these light sources the slide was placed on the stage and kept in the exact same position for all of the captures.

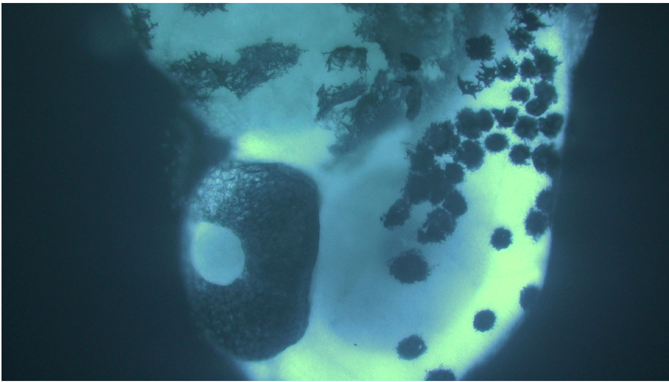


Image 6.1 (DAPI)

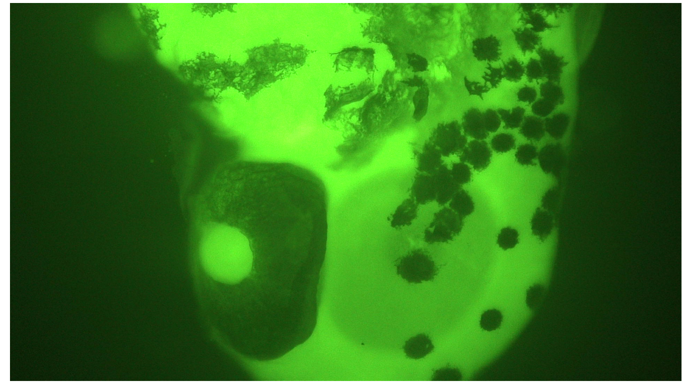


Image 6.2 (GFP)

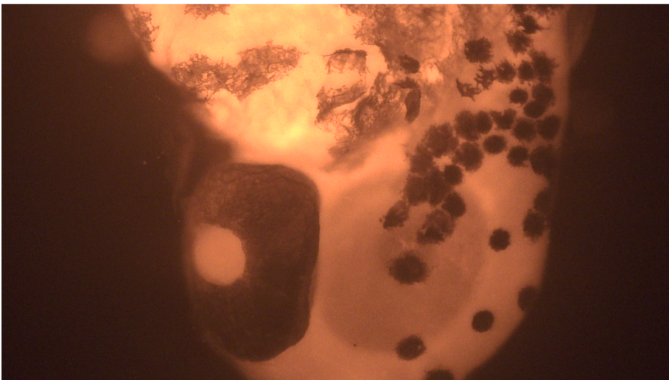


Image 6.3 (TRITC)

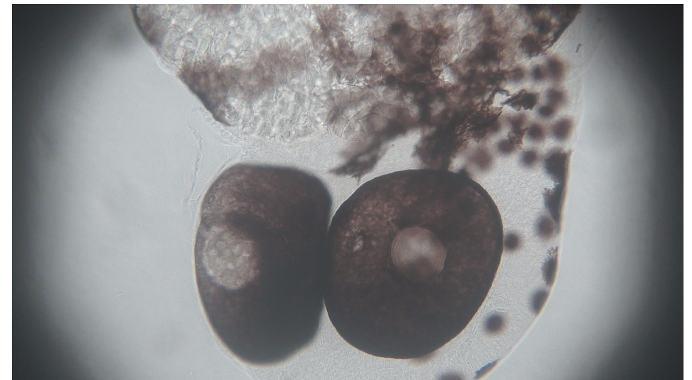


Image 6.4 (backlight)

Images 6.1-6.3 represent the different epi-fluorescence wavelengths while 6.4 was illuminated using the microscope's backlight. Some of the disparities are more subtle but they can still be compared. I enjoyed exploring the visual differences that the various light sources produced. For some specimens the visual differences between the light paths are staggering. An example of this is a specially prepared slide of blood cells ordered from Invitrogen. This slide is highly sophisticated as it has been treated with numerous stains to help illuminate different cellular structures. This slide was ordered for me by Dr. Ethan Carver and was quite expensive due to its quality.

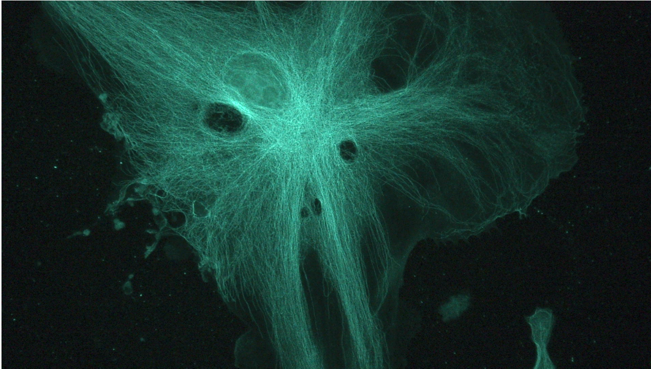


Image 7.1 (GFP)

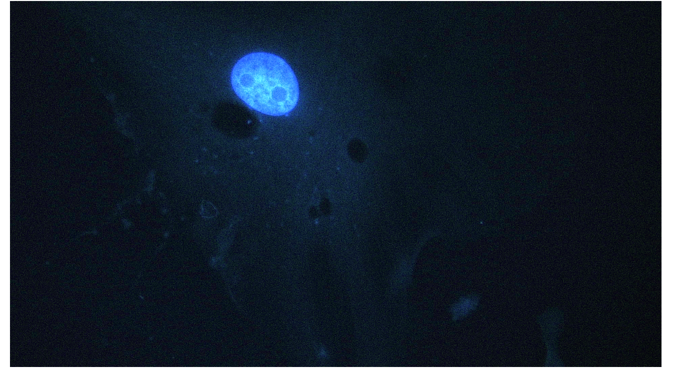


Image 7.2 (DAPI)

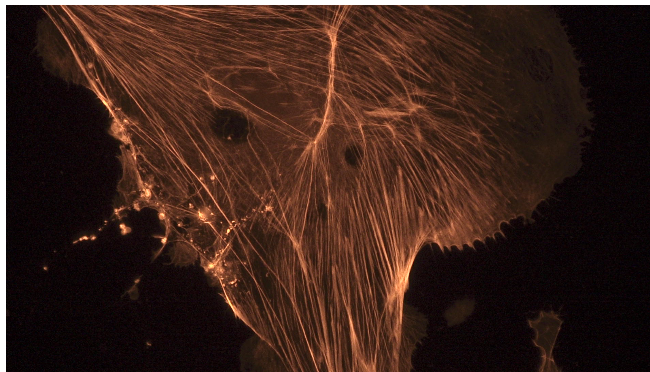


Image 7.3 (TRITC)

While images 7.1, 7.2, and 7.3 are all of the same subject, the visual outcomes of the epi-fluorescent channels are so different that programs like Helicon Focus are not able to successfully stack them into one image. Attempts to do so result in an image that does not accurately represent any of the individual photographs (7.4).

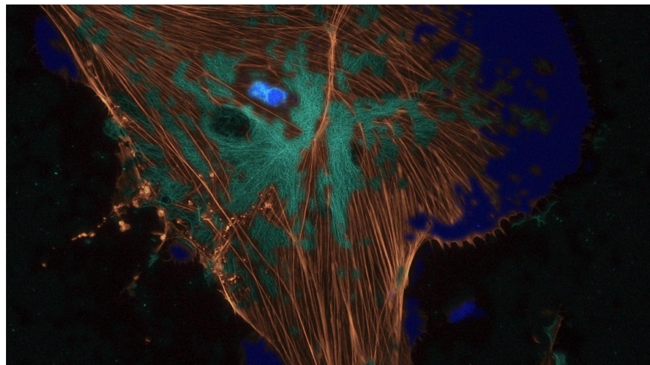


Image 7.4 (stack)

Confocality

This is where confacilty is the superior methodology of capture for such advanced slides. In fact, this slide of blood cells was intended to be used with a confocal microscope. Confocality works exclusively with slides under oil and objective lenses 40X and 60X. While the confocal microscope is capable of some baseline microscopy, its specialty is confocality. There are numerous advantages to confocal microscopy, including “the ability to control depth of field, [and] elimination or reduction of background information away from the focal plane” (Fellers). This microscope function utilizes a laser as its light source. Confocality was invented through efforts to improve upon fluorescent microscopy. Instead of exposing the whole specimen to intense light, the laser of a confocal scope is pointed at a singular microscopic area. A computer receives the information at that point then the laser moves to the next. It methodically scans across to capture and stitch together one full image. As explained in the article *Introduction to Confocal Microscopy,* the confocal microscope consists of numerous parts but also requires “[an external] computer for acquisition, processing, analysis, and display of images” (Fellers).

Due to the laser's danger to the human eye, as a safeguard, the ocular lenses are completely bypassed. With confocality the trinocular mounted camera cannot be used to capture these images, all imagery is collected through a computer program, Olympus FluoView. This application is run on a desktop computer that is directly connected to the microscope. Both the computer and the program are outdated by over a decade, but they still work in collecting photomicrographs. Unlike epi-fluorescence, under confocality, multiple light emission channels can be recorded at once. The computer program will even allow you to merge these channels in post-editing. This results in an image similar to that of epi-fluorescence but with the full range of detail and color of each light channel in one photo. Images 8.1, 8.2, and 8.3 represent three different channels of confocality while 8.4 is the image of the three channels combined.

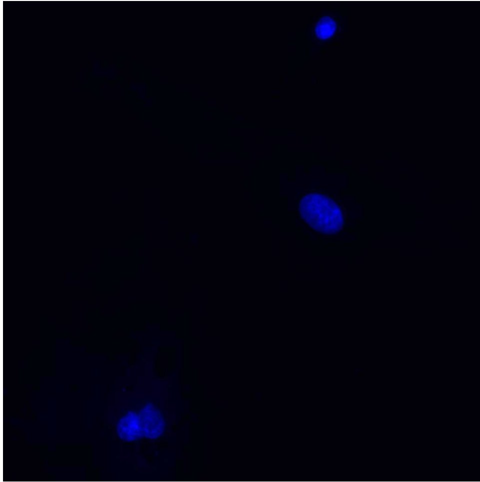


Image 8.1

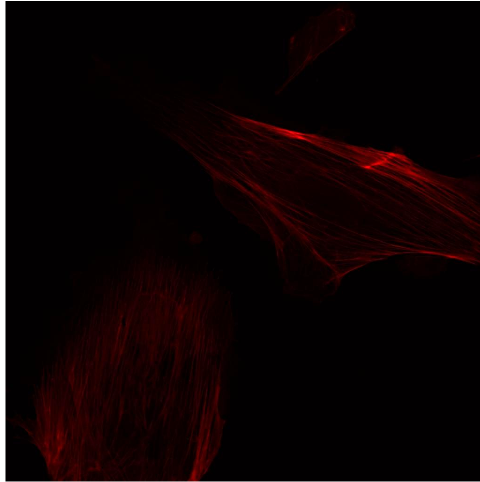


Image 8.2

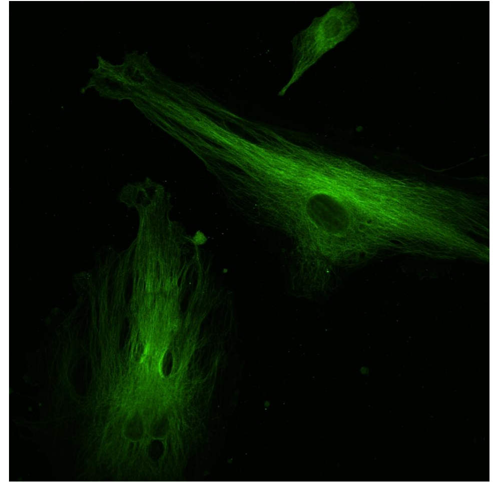


Image 8.3

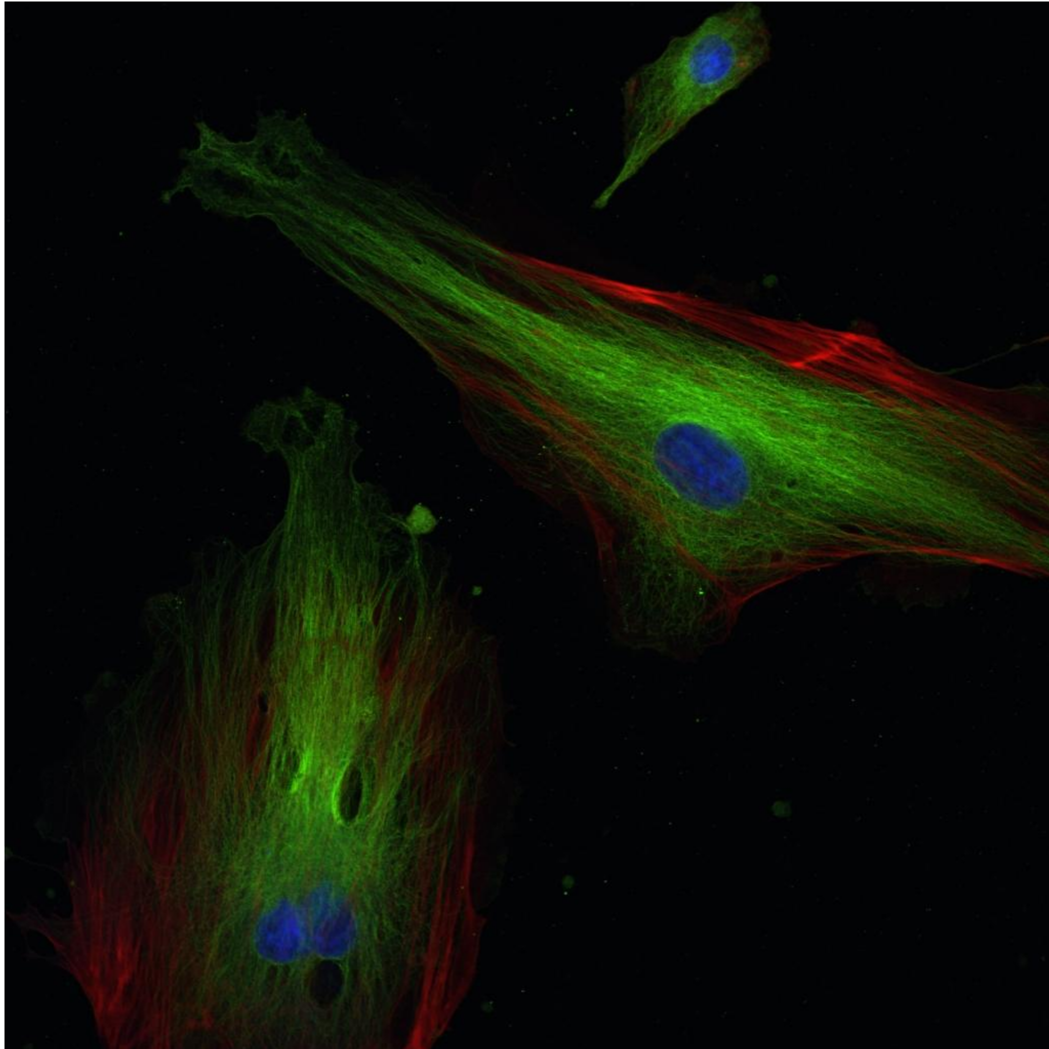


Image 8.4

The process of taking images under confocality is entirely different from the other capabilities of this microscope and took longer for me to become proficient. The computer does not show a live image but instead an updating scan of the image area. This makes adjusting the stage and focus of the scope more difficult than in the brightfield or epi-fluorescence functions. With confocality, it takes time and patience to bring an image into focus. Once you have the settings adjusted to your preference you start the capturing scan. Depending on the settings, the completion of a scan can take anywhere from 5 mins up to several hours. Extremely high-resolution scans could take the better part of a day to complete. My typical setting selection ranged from 5 to 15 mins. Throughout the scanning interval, it is imperative that the microscope not be disturbed. Even a slight shift of the table can cause the integrity of the images to be lost. I found it easy to lose an entire day to taking confocal images. It was a bigger challenge than any of the other formats, but my continual practice correlated to the increase in image quality.

Discussion

Overall, I learned that photomicroscopy requires both scientific and artistic skills. Through this thesis, I hoped to find examples of when science and art intersect. Instead, I discovered a realm in which they actually dependent on one another. I believe that photomicroscopy is a truly interdisciplinary field, both science and art are integral to the occupation. Science is necessary as it provides the foundation of understanding and access to equipment. Artistic concepts like composition, editing, lighting, and aesthetics are necessary for the creation of well-balanced photomicrographs.

As referenced in the sections above, I am not nearly the first person to declare this connection. This interdisciplinary argument for photomicroscopy is supported by literature like *Photomicrography as an Artistic Medium* by Nicolas Eubank, *Crossing Borders: the Path of Photomicrography towards Artistic Recognition* by Sandra Santos, *The Unseen Water: The Transmigration of Scientific Photography into the Domain of Art through Experimentation with the Scanning Electron Microscope* by Anastasia Tyurina, and *Micro Art* by Roberto Dabdoub. Most of the authors listed above worked to create their own photomicrographs

and experienced this firsthand. Contrastingly, *Crossing Borders* by Sandra Santos is a thorough literature review of the times photomicroscopy is acknowledged as art.

> We have shown that it was not until the twentieth century that photomicrography was seen unpretentiously as a form of artistic expression, as science and art were looked upon as two complementing and well-accepted sides of the same visual cosmos. (Santos, 2015, p. 11)

An excerpt from Eubank's thesis which I included in my background section, argues that a microscopist that lacks either scientific or artistic skills is equally handicapped. If a scientist were to take up microscopy they would need to learn elements of photography and art composition. If an artist were to attempt microscopy they would also need a scientific understanding of the equipment and methodology. In my experience, the field of science prepared me with a baseline understanding of microscopes. It also permitted my access to specialized laboratories. The author of *The Unseen Water: The Transmigration of Scientific Photography into the Domain of Art through Experimentation with the Scanning Electron Microscope* discusses this obstacle. Author Anastasia Tyurina, states that "artists who use photomicrography… [have] limited access to expensive equipment and well-equipped laboratories" which "contrast[s] with scientists, who generally have access to the sophisticated imaging technology commonly housed in research and academic institutions" (Tyurina).

In the early months of 2022, due to the Laboratory Team Leader, Joshua Solomon, and the Lab Lead, Ying Lu, I gained the opportunity to visit the General Motors Metallurgy Lab in Detroit, Michigan. I was granted access to their equipment for scientific-educational purposes on my interdisciplinary thesis. While in Detroit I had 12 hours in their lab where I was able to work on a 4K Ultra-High Accuray Digital Light Microscope, the Keyence VHX-7000. The capabilities of this scope far surpassed those of UTC's Olympus Fluoview FV-1000. The GM Metallurgy Lab had several of these powerful machines as well as a specialized SEM, the JOEL JSM-IT100. The Metallurgy Lab is worth an estimated $2,540,000, this difference in the lab equipment is a direct result of the respecting budgets of these organizations. It also reflects the limitation that artists might face when wanting to

use such high-tech equipment. While I was able to gain access to the lab through my thesis work, I question if an artist without a science background would have been granted the same privilege.

The Keyence VHX-7000 is a fully digital scope controlled through a computer screen and no ocular lenses. The Keyence has four objective lenses each with a magnification range. The lenses are as follows, 20X-100X, 100X-500X, 500X-2500X, and lastly 2500X-6000X. This scope allowed for the creation of images at a significantly higher magnification than the Fluoview which maxed out at 60X. Instead of a backlight, the specimens were illuminated from above, with LEDs built into each objective lens. This scope is largely automated and has many features that make captures quick and easy. The Scope had functions to autofocus, auto light, auto HDR, and even auto edit. On the Olympus Fluoview, a stacked image had to be made manually, each image extracted and then stacked with a third-party program. Contrastingly, the Keyence allowed for a custom focal range to be set and would then automatically take each image and stack them together. This scope could break down the focal range into hundreds of images which allowed for stacked images in ultra-high resolution.

The images below are small series that showcase the difference in magnification, resolution, and focal depth between these two scopes. Image 9.1 is a stacked image taken with the Olympus Fluoview under 10x magnification with external lighting. Image 9.2 is a stacked image taken with the Keyence at 500x magnification with internal lighting and a high-resolution setting, HDR (High Dynamic Range). The difference in quality between these two microscopes is also correlated with the active research coming out of these labs. The Microscope Laboratory at UTC is used in low-level research endeavors. Comparatively the GM Metallurgy Lab is used on a daily basis for the research and production of their products. A written copy of the conversation series titled *What is Research?* by Peter N. Miller, explores the relevance of research. He declares it critically important because it is “the heart of the modern world” (Miller).

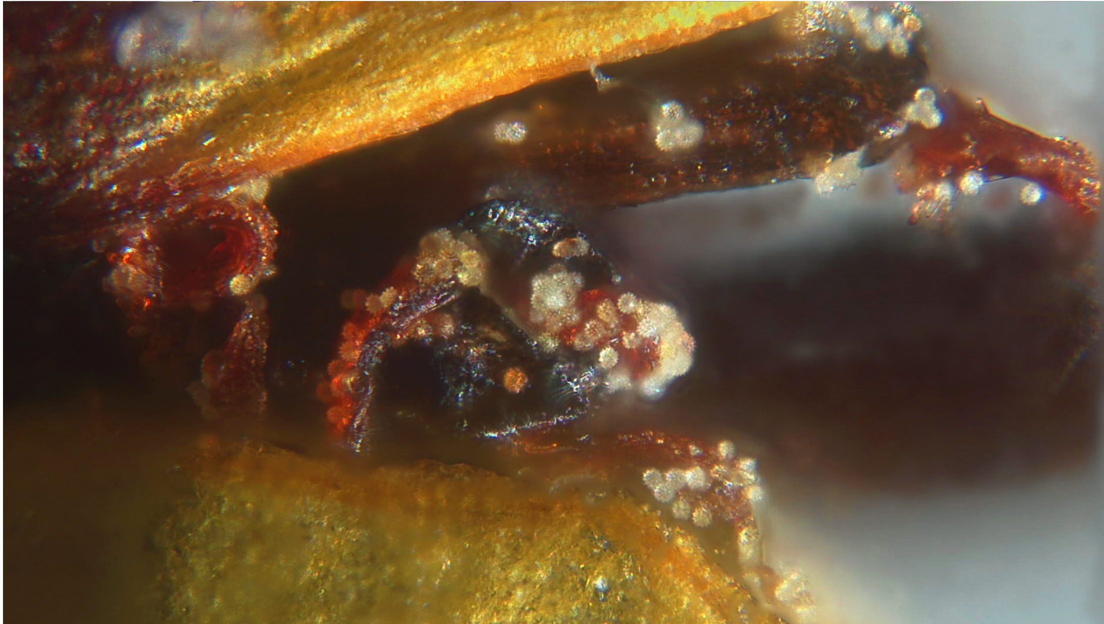


Image 9.1

Image 9.2

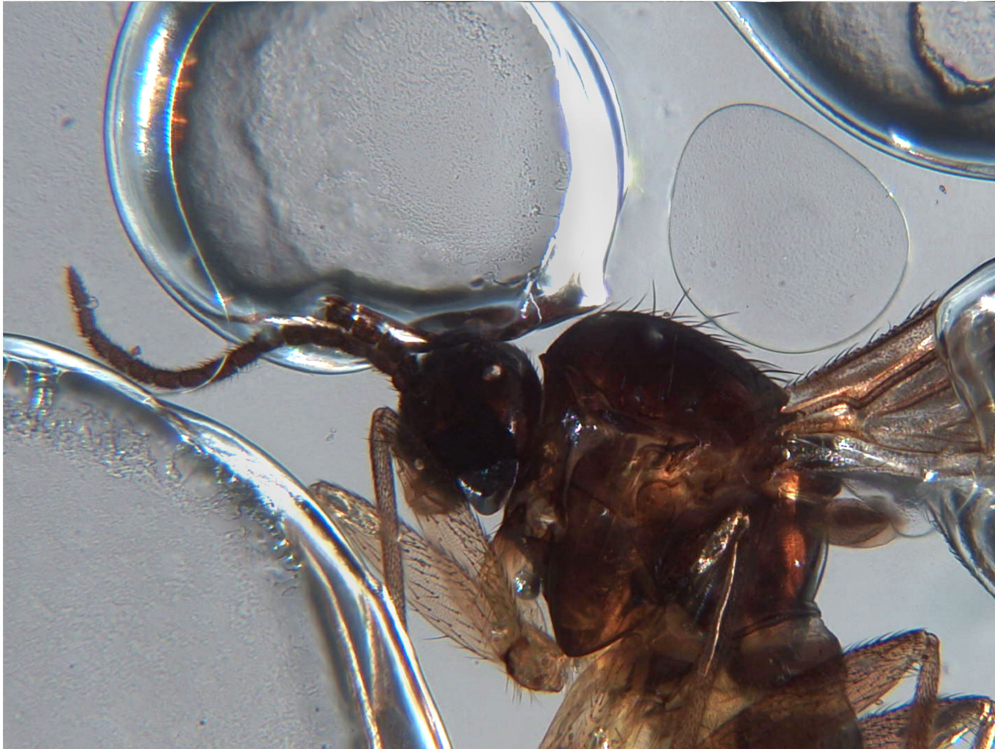


Image 10.1 (Fluoview-stack-4x-cropped)

Image 10.2 (Keyence-stack-150x-HDR)

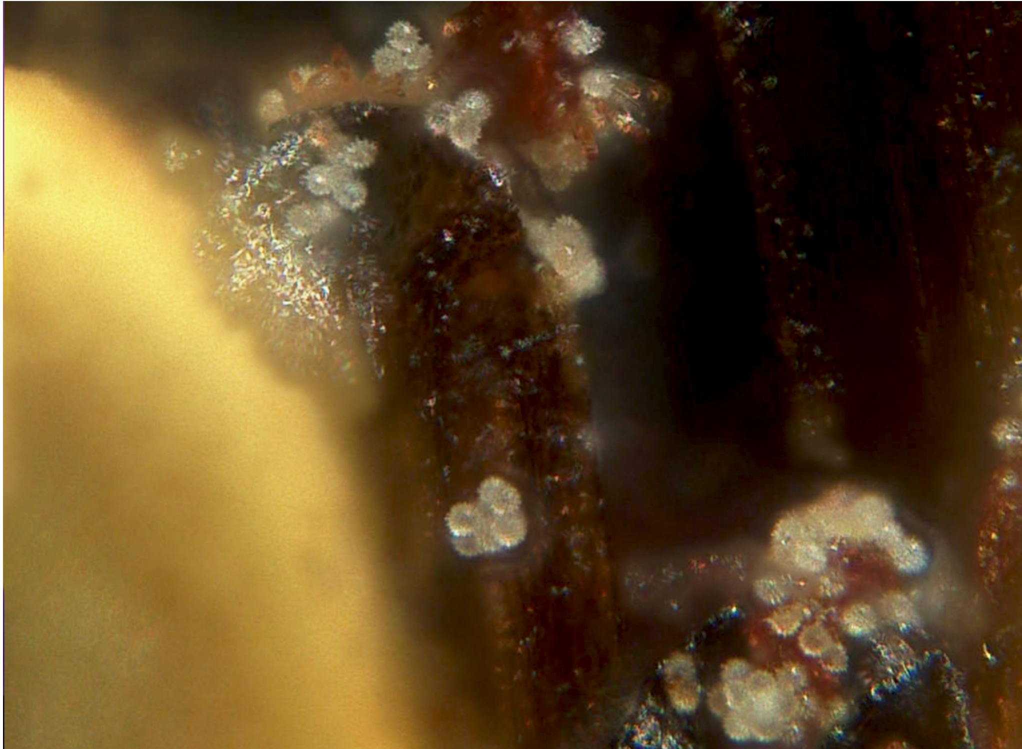


Image 11.1 (Fluoview-stack-10x-croped)

Image 11.2 (Keyence-stack-1000x)

Image 12.1 (Fluoview-stack-4x-Epiflourescence)

Image 12.2 (Keyence-stack-80x-HDR)

Through a discussion in *What is Research?* the panelists agree that research is something that anyone can do, it does not have to be restricted to scientific endeavors. Panelist Tom Joyce states that “trial and error is the research component that drives whatever the activity is” (Miller). The creation of art, including my photomicrographs in this thesis, follows this sentiment as well. Another panelist An-My Lê is a photographer with a background in biology. She felt that science was too narrow and that often times you “had to have a goal and stay within that goal” (Miller). An-My shared her appreciation for the flexibility of art, and the freedom to follow whatever inspires you. The artistic freedom that I experienced throughout my thesis largely drove the creation of the work. Due to the art side of the interdisciplinary topic, I did not need to narrow my subject matter. I followed my curiosity and observed as many subjects as I could get my hands on. I allowed artistic inspiration to direct the project, rather than a specific scientific investigation. Author and photographer Anastasia Tyurina, was recognized in the 2016 Images of Distinction in the Nikon Small World competition. In her thesis, *The Unseen Water,* she talks about the relevance of being an artist and not a scientist or professional microscopist, which amongst her competitors was rare.

> It is a crucial point of difference between my work and that of other participants that the specimen I photographed was not involved in any scientific investigation related to it; it also was not a part of any technical work associated with microscope performance, such as testing. Rather, my only intention for working with the specimen was to create an artistic image of it—to make an artwork. Therefore, I used the [microscope] as a creative tool. (Tyurina, 2017, p. 12)

Conclusion

Nonetheless, the scientist or professional microscopist who enters such a competition, do also utilize artistic skills. Their field of origin will likely influence the subject matter, however, the act of taking and refining photomicrographs requires that they be well versed in photographic techniques. They themselves can be called artists too, they must consider composition, lighting, color, and aesthetics. Many photomicrographs are

highly manipulated in editing software like Adobe Photoshop. All such skills are correlated to art rather than science.

Photomicrography is a fascinating middle ground between the fields of art and science. Even individuals who start with a background in one field will eventually gain skills in the other. I was fortunate enough to have a background in both science and art. In pursuing a scientific degree I gained exposure to many fields of study. I often used elementary microscopes as a research tool in various laboratory classes. The microscopic world always fascinated me, I often took photographs with my phone through the ocular lenses. My experience as a photographer influenced even those early days of microscope use. I patiently worked to get a steady image and good framing. Taking images through the ocular lens and taking images with a trinocular mounted camera hardly compare. After transitioning into the field of photomicrography I was able to call upon even more of my photography skills. While the mechanics of the microscopes were nuanced I relied on my understanding of cameras, artistic composition, and editing. The production of my photomicrographic body of work utilized both of my backgrounds. The supportive literature mentioned above furthers my argument that photomicrography is both artistic and scientific. Through this thesis, I discovered a field that is a true blend of my greatest passions.

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