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3D Modeling Techniques for Print and Digital Media

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ROCHESTER INSTITUTE OF TECHNOLOGY

A Thesis Submitted to the Faculty of

The College of Health Sciences & Technology Medical Illustration

In Candidacy for the Degree of

Master of Fine Arts in Medical Illustration

3D Modeling Techniques for Print and Digital Media

by

Megan Ashley Stephens

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Thesis Title: <u>3D Modeling Techniques for Print and Digital Media</u>

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Abstract:

In developing my thesis, I looked to gain skills using ZBrush to create 3D models, 3D scanning, and 3D printing. The models created compared the hearts of several vertebrates and were intended for students attending Comparative Vertebrate Anatomy . I used several resources to create a model of the human heart and was able to work from life while creating heart models from other vertebrates.

I successfully learned ZBrush and 3D scanning, and successfully printed 3D heart models. ZBrush allowed me to create several intricate models for use in both animation and print media. The 3D scanning technique did not fit my needs for the project, but may be of use for later projects. I was able to 3D print using two different techniques as well.

List of Illustrations:

Introduction:

3D imaging techniques are playing an ever-growing role in the allied health field, especially in medical illustration. In developing my thesis goals, I wished to explore several aspects of 3D imaging. I also aimed to learn techniques that were not included in the required Medical Illustration curriculum, including using ZBrush to 3D model, 3D scan an object, and 3D print. Since I was new to the software and tools, I opted to use heavily documented and recognizable subject matter, the human heart. I later expanded my work to include hearts from other vertebrate species to show how 3D models can be used to compare their anatomy.

Models created this way can be used as learning tools for students and professionals, depending on their level of detail. I was looking to use the information conveyed in the models I created, but I think my methods used are valuable learning objectives as well. Techniques that I explored can be used by myself, along with future students, to build our own art and educational models.

Background:

In choosing hearts to use for the comparative anatomy portion of my project, I tried to choose representative samples of two, three, and four chambered hearts. For Comparative Vertebrate Anatomy Lab, we dissected a dogfish shark, a mudpuppy, and a pigeon, and they seemed to fit my needs, and I had samples to work from.

The dogfish shark, like all fish, has what is commonly referred to as a single pump structure, as it has two main chambers. To the untrained individual it is often considered to have four, as the sinus venosus and the bulbus arteriosus are considered to be chambers, but were not

included because they are considered evolutionarily to be the precursors to third and fourth chambers, respectively (Kardong 2015). They do not join the other two chambers parallel to one another to form one organ as bird and mammal hearts do, rather the sinus venosus is anterior to the atrium, and the bulbus arteriousus lies posterior. Traditionally this structural organization gives rise to an s-shaped organ, rather than the traditional heart-shaped one which most individuals are familiar. Deoxygenated blood enters the thin-walled atrium via the sinus venosus, which provides the pacing of the heart's contractions. As blood flow continues throughout the heart, it flows into the thick-walled ventricle and then out through the bulbus arteriousus. (De luliis 2011). It is important to note that, despite not being a chamber, the bulbus ateriousus is responsible for decreasing the amount of pressure generated from the blood as it exits the heart and transitions into the gills. After all, gill structure can be considered "fragile" in comparison to the heart itself and they may become damaged if the pressure is excessive. It is for these reasons that the two-chambered heart has been selected to demonstrate the evolutionary (structural) differences between various vertebrate organisms.
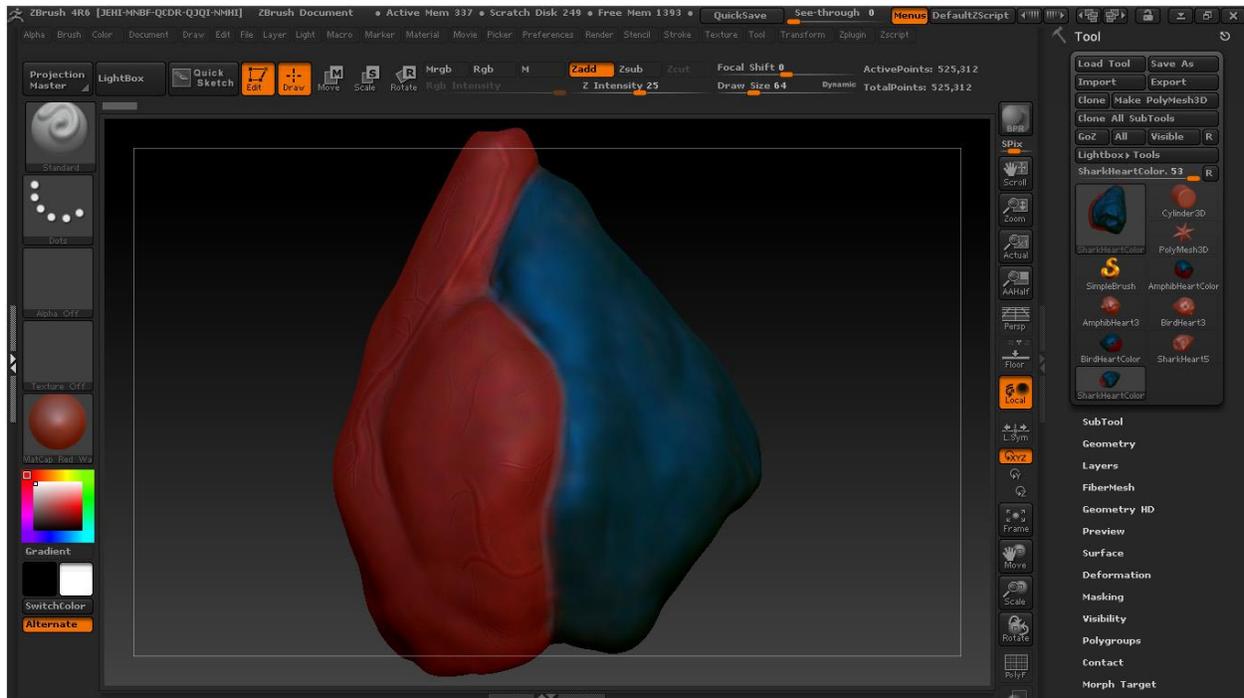
Figure 1: Colorized Dogfish Shark heart model in ZBrush.

The mudpuppy heart, like all other amphibians and most reptiles, has three main chambers. The ventricle along with the left and right atria I decided were the most pertinent to the project, given that the dogfish shark only included what are considered to be atria and ventricles. Unlike the shark heart, though, the mudpuppy's heart does contain a sinus venosus and conus arteriosus (Kardong 2015).
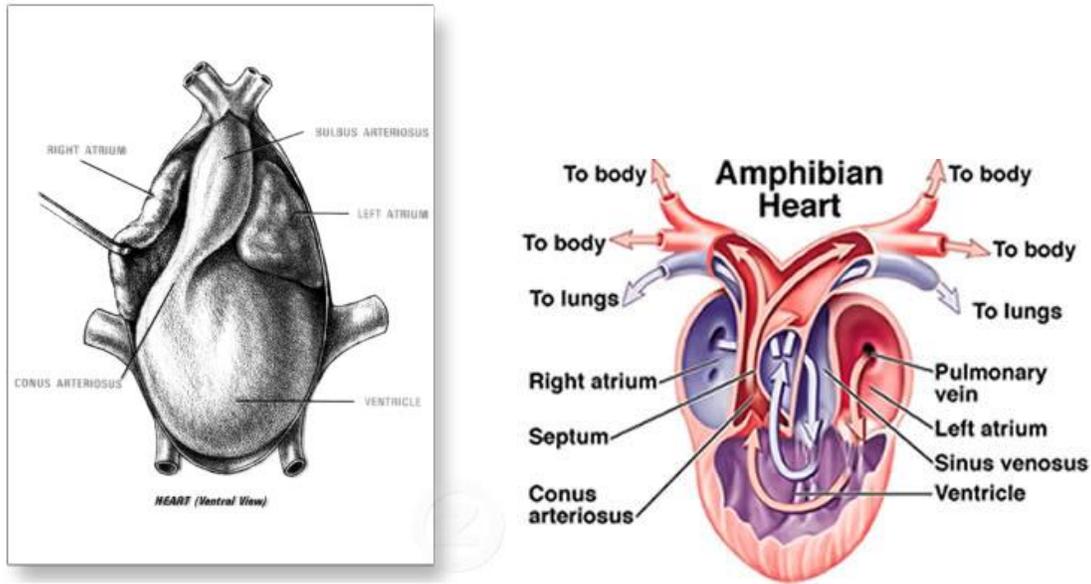
Figure 2: Amphibian heart diagram.
(http://livelikedirt.blogspot.com/2010/04/necturus-anatomy.html)
(http://dtc.pima.edu/blc/182/lesson11/11step3/11step3images/amphibianheart2.jpg)

The addition of the second atrium allows for a pulmonary circulation. Blood travels from the pulmonary vein and into the left atrium. From there it progresses into the ventricle, and out to the conus arteriousus in pulmonary circulation, and in systemic circulation blood flows from the sinus venosus, to the right atrium, the ventricle, and out to the conus arteriosus in the mudpuppy heart (De luliis 2011). It should also be understood that the addition of another atrium was not the only structural change of the heart. One of the largest changes that can be seen externally is the conversion of the main vein exiting the heart into an artery. Though not covered in this project, it should also be mentioned that changes also occurred internally, like the presence of valves between the chambers and changes within the cardiac muscle. This promoted the return of oxygenated blood to the heart. This movement and the addition of the second atrium allows for the presence of both oxygenated and deoxygenated blood found within the ventricle of the heart. This is a key element in the evolutionary significance of this type of heart, as it

provides advances in cardiovascular activity as organisms move from a primarily aquatic
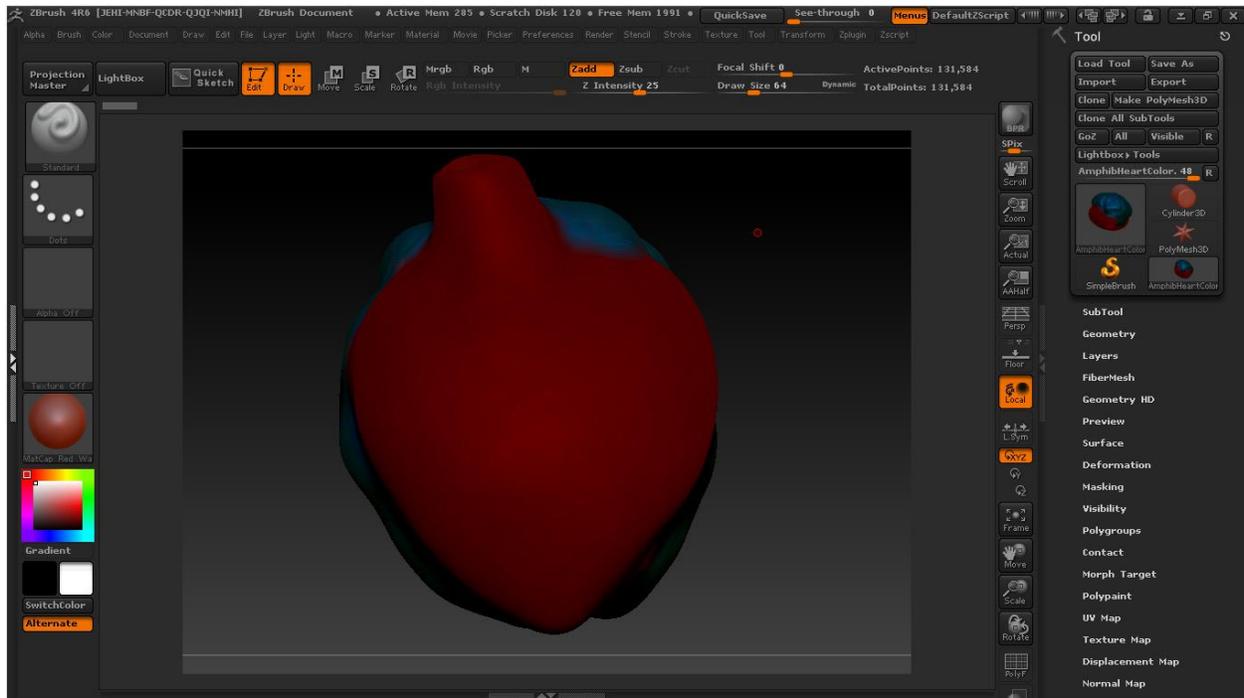
ecosystem to a terrestrial one.

Figure 3: Colorized Mudpuppy heart model in ZBrush.

The pigeon heart is very much like the mammalian heart in that it has four separate

chambers. From the mudpuppy's three chamber system, the avian and mammalian hearts have

developed a septum in the ventricle, dividing it into right and left ventricles (Kardong 2015).
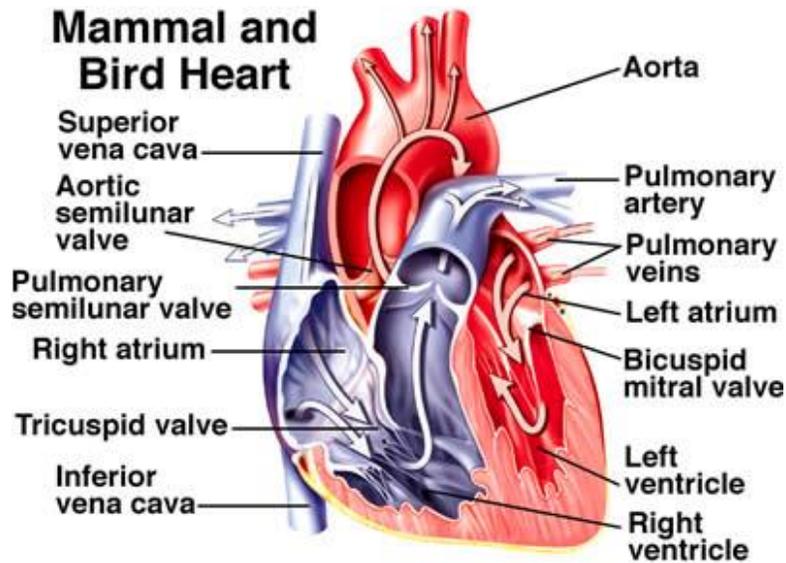
Figure 4: Mammalian heart diagram.

(http://dtc.pima.edu/blc/182/lesson11/11step3/11step3images/mammalheart2.jpg)

The ventricles and atria on the right and left portions of the heart are functionally different. The right side functions as a pulmonary pump, sending deoxygenated blood to the lungs, whereas the left side serves as a systemic pump, receiving oxygenated blood from the lungs and pumping it out to the rest of the body. Blood flows from the body to the right atrium, to the right ventricle, to the lungs, back to the left atrium of the heart, to the left ventricle, then out to the rest of the body (De luliis 2011).
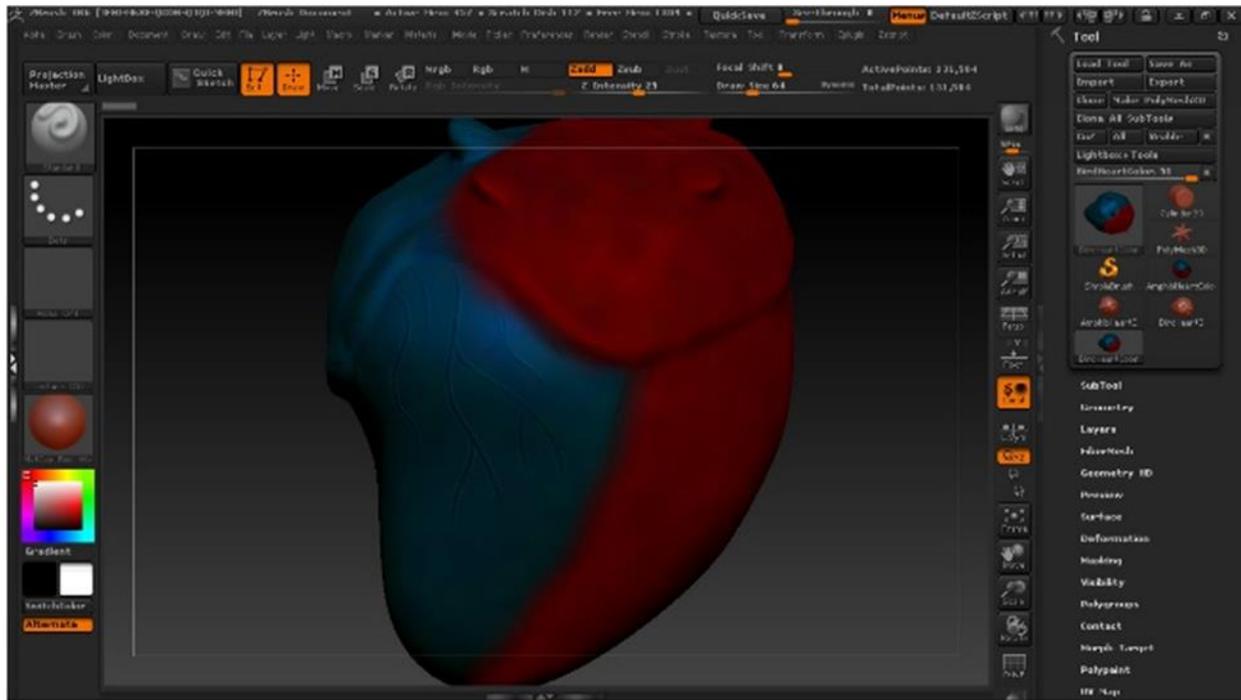
Figure 5: Colorized pigeon heart model in ZBrush.

Techniques:

Having taken courses using Maya and Mudbox, I wanted to expand my skills to more 3D modeling programs. I decided to use ZBrush to make more detailed models for use in animation and 3D print media. I completed two tutorials to learn the program, ZBrush 4 Essential Training (Kittleson 2015) from Lynda, and Beginner's Guide to ZBrush (Marshall 2015) from Digital Tutors. I chose to depict the human heart, primarily using the Atlas of Anatomy (Gilroy et. all 2012) and the Color Atlas of Anatomy (Rohen et. al. 2011) as my reference material to build my model.

I started building my model using a ZSphere, a sphere in ZBrush that's a common starting point for building models. Using principally the "simple" and "move" brushes, I was able to

sculpt the form I wanted in much the same way as one would sculpt clay. The "Zadd" and

"Zsub" settings at the top of the screen allow mass to be added and subtracted, respectively, each

time the user clicks and drags on the model. ZBrush also allows pressure sensitive tablet settings

to be enabled, which was particularly useful when making structures such as vessels that

gradually become smaller or larger. The size and intensity of the brush strokes can be adjusted
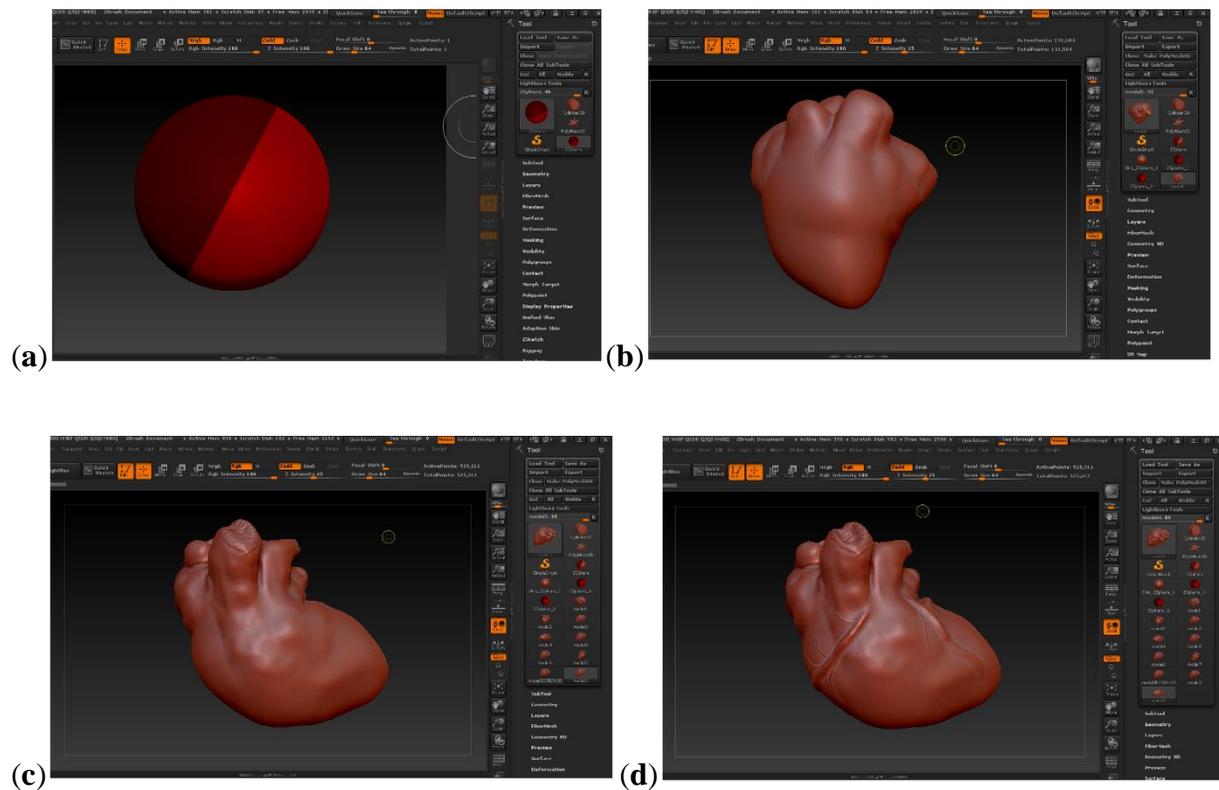
as well, along with the brush type and texture.

Figure 6: Progression of the human heart model. Image (**a**) represents the ZSphere starting

point, while images (**b**), (**c**), and (**d**) represent the progression to a more complete model.

Increasing detail with each model, I began to refine the structures at each step and add in details such as the coronary vessels. Rough areas were smoothed out by holding the shift key while using the brush function. My final model can be seen in Figure 7.
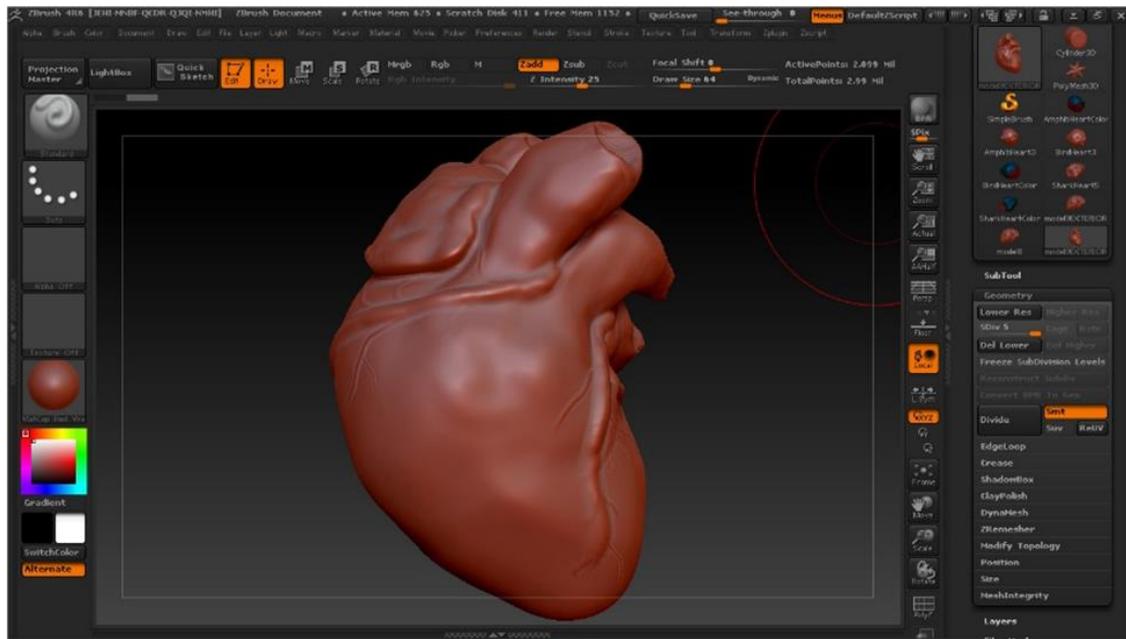

Figure 7: Human heart modeled in ZBrush.

Upon beginning classes for the Spring 2015 semester, I found that 3D scanning had become available to College of Imaging Arts and Sciences students. Given that I also had begun a Comparative Vertebrate Anatomy class with a dissection lab component, I thought combining the two would be a perfect addition to my human heart study in ZBrush. Scanning and printing various types of hearts from the representative species we dissected in class would easily show a side by side comparison of anatomy.

With the help of another student, Grace Southerland, I was able to use the Makerbot 3D scanner that the glass department has access to. The scanner works by taking data using a laser (Figure 8) and produces a workable 3D model in STL format that can be opened in most 3D modeling software.
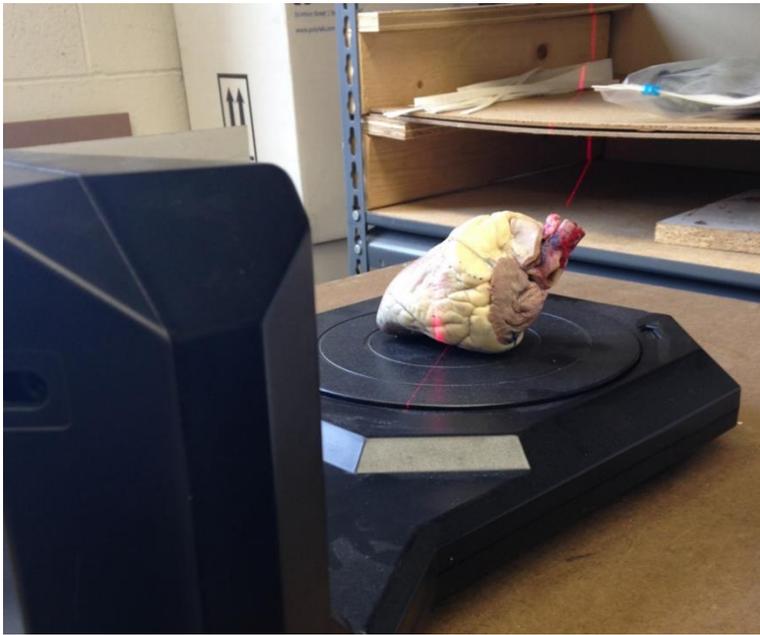

Figure 8: MakerBot 3D scanner with sheep's heart as example.

However, I found that the scanner was unable to record the amount of detail that I was looking for in my models. Also, the 3D scanner struggled to record the information on smaller objects. At approximately 3 inches square or less the scanner could not produce recognizable models. For these reasons I decided to make the three comparative anatomy models from scratch in ZBrush as I had done with the human heart. Though I did not end up using any models taken from 3D scans in the final product, I did learn a good deal about the machine and scanning process that I can apply elsewhere. Objects ideal for scanning should not be reflective or have overlapping or hidden areas. Shiny or damp surfaces can reflect the laser light, preventing it

from collecting accurate data. Undercuts, or parts that block and overlap others, interfere with accurate data readings. Multiple scans can be taken and compiled into one model in some instances to account for inaccuracies caused by these issues.

For the comparative anatomy portion, I was lucky enough to have access to hearts removed from shark, mudpuppy, and pigeon dissections that we did in Comparative Vertebrate Anatomy Laboratory. I supplemented the direct reference with a comparative anatomy text (Kardong 2015) and dissection manual (De Iuliis 2011). I modeled the exterior portions of the two, three, and four chambered hearts (Figures 9 and 10) by observing them from life, and used the functional anatomy concepts from the texts to inform my visual decisions.
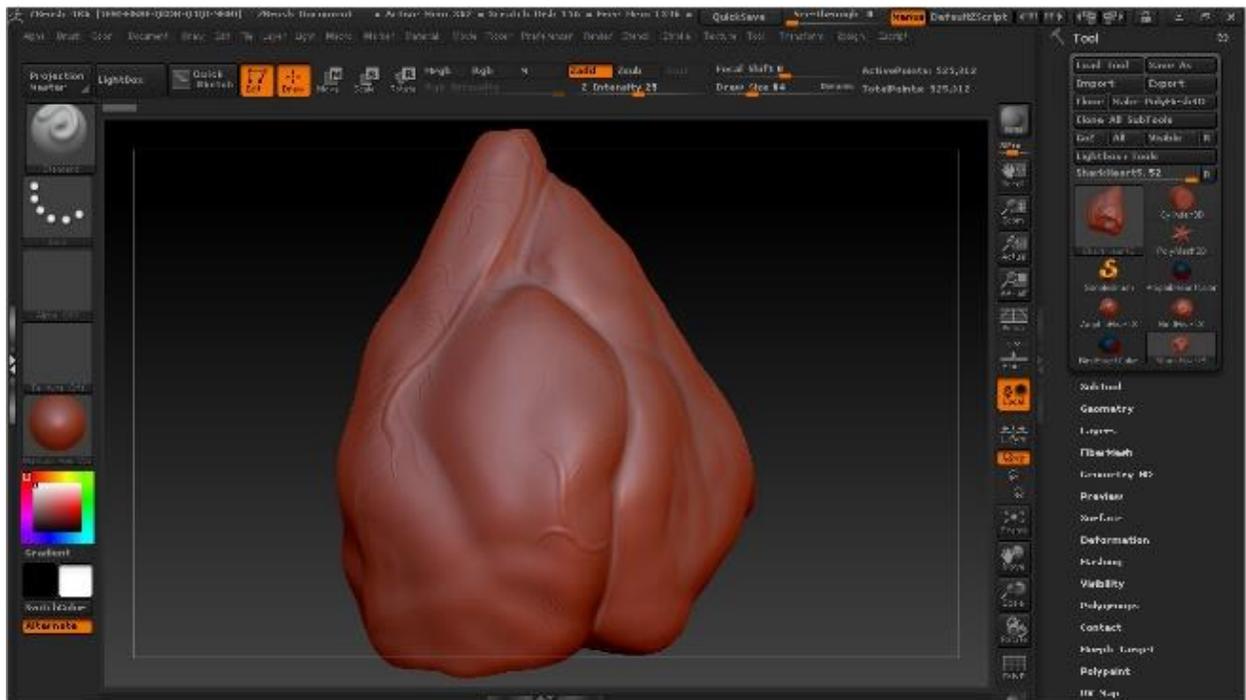

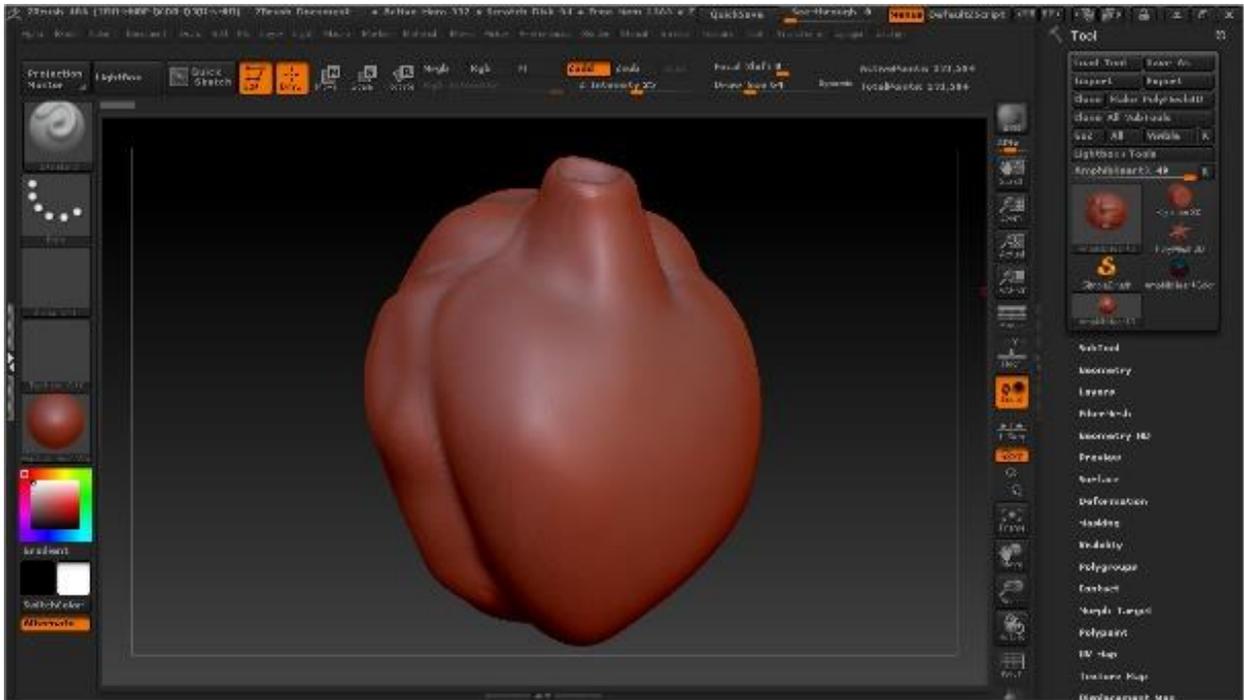**Figure 9:** Dogfish shark model in ZBrush.

Figure 10: Mudpuppy heart model in ZBrush.

Shapeways is a company that allows customers to upload 3D models to their website and have them printed and shipped to them. I was able to upload fairly complicated models, but there was a limit to how much geometry, and therefore how much detail, the model had for the website. The model I initially created had five levels of subdivisions, and I had to reduce it to four for the model to successfully upload. Models are broken into polygons, and subdividing them allows for more intricate models; each subdivision breaks each polygon into two, doubling the number of polygons and increasing the file size with each division. Reducing the geometry sacrificed the model some of its subtlety of form, but was necessary in order to reduce file size for upload to the Shapeways website.
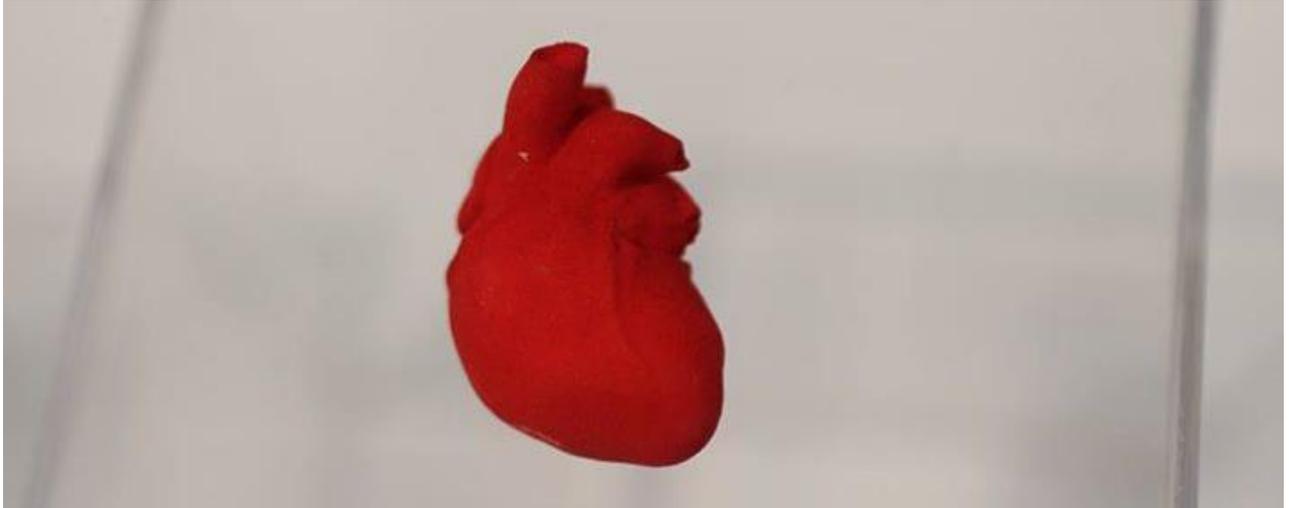
Figure 11: Human heart Shapeways print in "red polished strong and flexible plastic."

I found that my local library, the Fayetteville Free Library in Fayetteville, New York, offers affordable and hands on 3D printing services. They have several Makerbot units that produce PLA plastic prints (Figure 11).
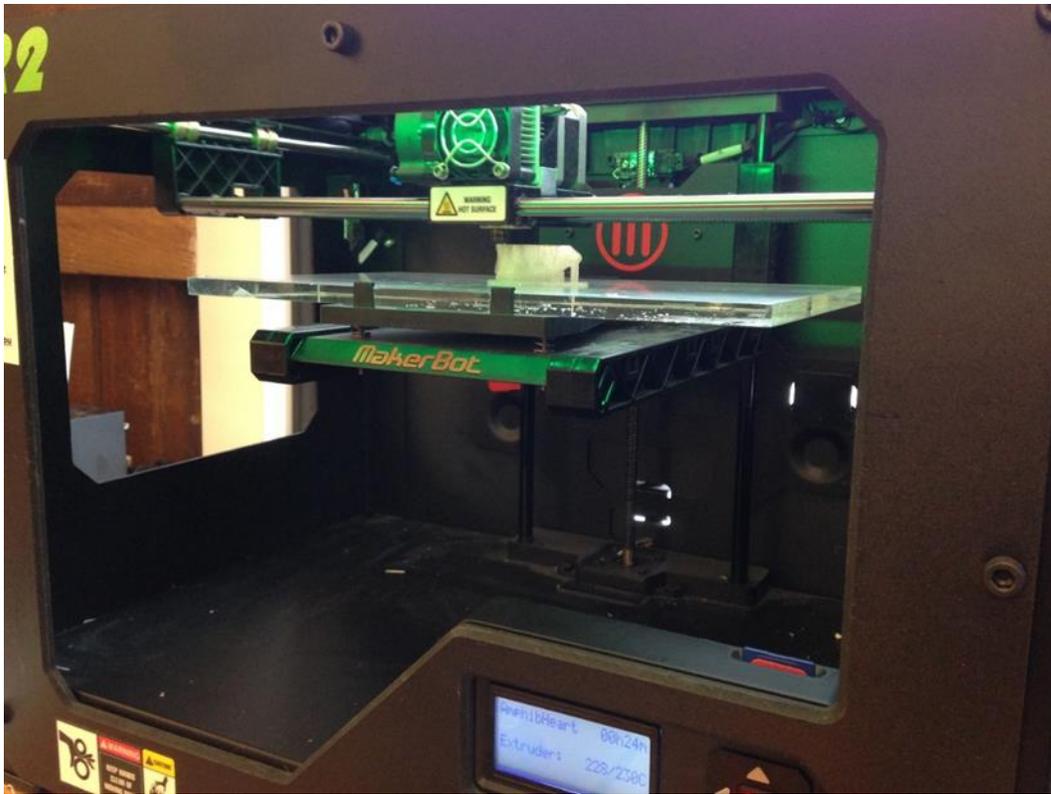
Figure 12: MakerBot 3D printer producing a dogfish shark heart.

    I was able to produce more prints given that the cost was so much lower; the library only charges for the cost of the plastic used, and not for the printing time as well. The Makerbot 3D printer will also make the model hollow with a honeycomb pattern on the inside, further reducing material use and cost. The PLA plastic, however, does not allow for a high amount of detail since it prints without a substrate.
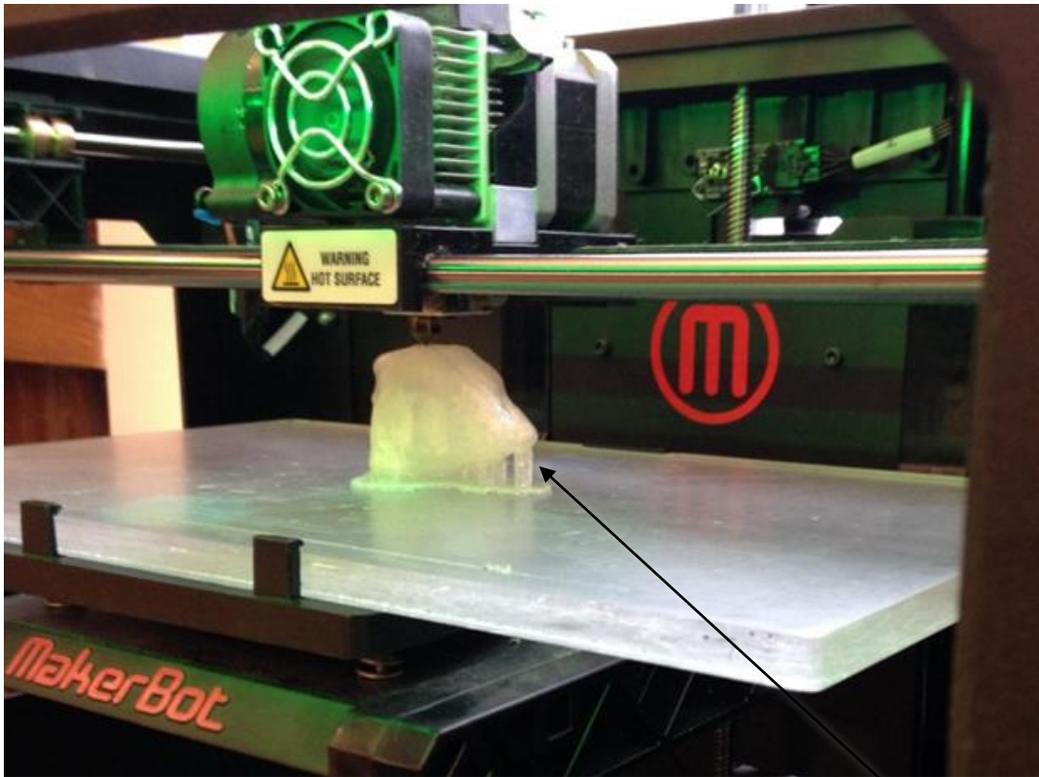
Figure 13: MakerBot 3D printer producing a dogfish shark heart, shows strut for support.

The lack of substrate also means that models with any pieces that have elevated surfaces need to be supported, so struts are printed as well that need to be broken off and filed down once it is printed (Figure 13). It also limits you to single color printing, unlike some machines that offer full color 3D renders. The Makerbot machines are more accessible though, and allowed me to be more involved in the printing process than when I used Shapeways.

The Shapeways printing procedure was the more costly of the two I used, given that the material itself is charged for by cubic centimeter, and when you increase the surface area of a model by a factor of two, the volume quadruples. I would have liked to produce the human heart at life size in that medium, but budget restrictions forced me to print at a smaller size. The level of detail was maintained, though, with their "Strong and Flexible Plastic" and their "Red Polished Strong and Flexible Plastic," the two materials that I ordered prints in. This material

prints in a substrate that is then removed from the model, which allows for higher detail and more freedom to create unsupported appendages on models. I found that the Makerbot models tended to lose fine detail more so than the Shapeways models, but given access to a Makerbot printer, is a faster and more economical way to print.

Lastly, with my models digitally created and printed, I wanted to display them in an animation as well. I created turntable animations for them all, including ones that I had colorized in ZBrush to demonstrate oxygenated and deoxygenated blood flow. They were animated to spin on a turntable, giving the viewer a full view of each of the models, along with labels for the relevant anatomy.

Conclusion:

In future work, I would like to print different models and be able to use them in a classroom setting. An intriguing direction would be uploading a collection of models to the MakerBot or Shapeways sites so that models could be ordered remotely; someone could download a stereo lithography, or STL, file and print it themselves if they had access to a 3D printer, or have it printed and shipped to them. STL file formats are ideal for single color 3D printing because they only contain data concerning the model's 3D structure, without the unnecessary color or texture information that is included in other 3D file formats. Also, as full color 3D printing expands and becomes more affordable, it would greatly enhance the teaching ability of the models. For instance, the red heart I printed (Figure 11) could show oxygenated and deoxygenated blood paths by using representational coloration.

Overall, I am pleased with the final outcome of the project, and I met my learning objective goals. Not all the procedures worked as I had hoped, such as the 3D scanning, but I still gained a working knowledge of the technology and techniques involved. I was able to develop skills in modeling in ZBrush, 3D scanning, and two types of 3D printing.

Sources:

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