Table 1: **Material of Replaceable Component Design Matrix:**

	Weight	**PLA**		**ABS**		**PETG**	
Mechanical Accuracy	25	5/5	25	2/5	10	1/5	5
Strength	20	3/5	12	5/5	20	2/5	8
Ease of Fabrication	20	5/5	20	2/5	8	4/5	16
Texture	15	4/5	12	3/5	9	2/5	6
Disposability	10	5/5	10	1/5	2	3/5	6
Cost	10	5/5	10	3/5	6	2/5	4
Total	**100**	**89**		**55**		**45**	

Criteria Definitions:

Mechanical Accuracy: Mechanical accuracy refers to how similarly the printed plastic can mimic the mechanical properties of native bone tissue. A plastic with a tensile strength comparable to bone (67 MPa at the least) and similar density would score highest. Mechanical accuracy is weighted highest at a 25 because it is important that the bone model accurately represents native bone for practicing the procedure.

Strength: Strength refers to how well the material holds up against the needle. The bone model needs to be able to be punctured at least five times before the section of the proximal humerus is replaced, a material that is too brittle will not stand up to multiple punctures. A material that is not brittle would score highest. Strength is weighted at a 20 because it is important that the material can stand up to five punctures to increase the usability of the model.

Ease of Fabrication: Ease of fabrication refers to how easily and quickly the material can be printed. A material that prints at a high quality with minimal modification to print settings to make it accessible for Veterinary School staff to quickly print replacement components is desired. Ease of fabrication is weighted at a 20 because the material must be feasible for someone not previously familiar 3D printers to work with.

Texture: Texture refers to how similar the material is to the feeling of native bone, accounting for the adherence between layers of the print, flexibility, and interaction with the needle. A material with similar flexibility and surface finish to bone is desired without need for additional post print processing. Texture is weighted at a 15 because the surface finish should be similar to bone to best mimic the procedure.

Disposability: Disposability refers to how sustainable the material is and the ease of disposing of the replacement components. Since the proximal humerus is replaced every five punctures, a lot of plastic waste may be created. A material that is biodegradable and/or recyclable would score highest in this category. Disposability is weighted at a 10 because it is important that the waste material from the model can be disposed of in a sustainable manner.

Cost: Cost refers to how much the 3D printer filament typically costs per spool. Since the client will be printing a large volume of replacement components, it is important to keep the ongoing cost of material low. A filament that is low in cost per spool would score the highest. Cost is weighted at a 10 because the client desires a low cost prototype solution.

Materials Design Matrix Summary:

Polylactic acid (PLA) scored the highest in the categories of mechanical accuracy, ease of fabrication, texture, disposability, and cost. It scored the highest in mechanical accuracy compared to Acrylonitrile butadiene styrene (ABS) and Polyethylene terephthalate glycol (PETG) because of its ability to mimic the characteristics of native bone tissue in tensile strength. PLA is also cheaper than both ABS and PETG and takes the least amount of time to fabricate in a 3-D printer. Given the versatility of PLA structures and the qualities of the material itself, it scored the highest in the category of texture due to the range of patterns, textures, and layers it can be used to print.

ABS scored the highest in the category of strength due to its capacity to have a large tensile strength. However, it scored lower than PLA for mechanical accuracy because it may not accurately represent native bone tissue because its tensile strength value is higher than that of bone. This would also contribute to a model made of ABS to be more rigid than bone tissue, thus being less accurate than PLA in terms of tensile strength and elastic modulus. Compared to both PETG and PLA, ABS takes the longest to fabricate in a 3-D printer. Additionally, the disposability of ABS was rated very low out of all the material options because it is not biodegradable and can only be recycled a few times before it’s rendered unusable. Considering the frequency with which the replaceable component will need to be replaced, this is an important factor to consider. It also costs slightly more than PLA, but lower than PETG.

PETG was rated the lowest overall based on our grading criteria. It scored the lowest in mechanical accuracy because the highest tensile strength it can reach is lower than that of bone; it is also more elastic than PLA or ABS. PETG has the ability to be more brittle than PLA or ABS if printed incorrectly, and may be slightly deformed upon repeated use because of its low tensile strength. A lower tensile strength would not mimic the feeling of native bone; thus PETG scored the lowest in Texture. While PETG does not print as fast as PLA typically does, it prints faster than ABS and was thus scored higher in ease of fabrication. While not biodegradable like PLA, PETG can be recycled significantly more times than ABS, and scored higher than ABS for disposability. PETG was rated the lowest for cost because it is the most expensive material to buy out of the three options.

In conclusion, because PLA was given the highest overall score, it is the material that has been chosen to fabricate the replaceable component in our veterinary bone marrow aspiration model.

***Table 2:* Replaceable Component Design Matrix:**

	Weight	**Screw Method**		**Slide Method**		**Velcro Method**	
Joint Interference	20	2/5	8	5/5	20	1/5	4
Ease of Fabrication	20	2/5	8	4/5	16	3/5	12
Ease of Use	15	2/5	6	4/5	12	3/5	9
Durability	15	2/5	6	4/5	12	2/5	6
Bone Marrow Access	15	5/5	15	4/5	12	2/5	6
Cost	10	2/5	4	5/5	10	3/5	6
Safety	5	4/5	4	3/5	3	3/5	3
Total	**100**	**51**		**85**		**46**	

**Drawings of the designs are being worked on and will be put into the matrix for the report/presentation*

Criteria Definitions:

Joint Interference: Joint interference refers to how easily replaceable the removable component is with respect to the shoulder joint, while still allowing the joint to be articulable. The section of the proximal humerus will need to be replaced frequently, so design that does not require any involvement of the shoulder joint to be replaced would score the highest. Joint interference is weighted at a 20 because the component must be easily replaceable without much interference with the shoulder joint.

Ease of Fabrication: Ease of fabrication refers to how easy the design is to model, 3-D print, and assemble. This includes the time it takes for the 3-D printer to fabricate the design, which is influenced by the size, density, and detail of the replaceable component. It is also important that the design can be replicated on different 3-D printers, and methods with a reduced need for exact accuracy with printing would score higher. Ease of fabrication is weighted at a 20 because it is important that the full design is feasible to fabricate within the semester and that the replaceable components are able to be easily fabricated by the client.

Ease of Use: Ease of use refers to how easily the components can be replaced and how easy it is for the Veterinary student to interact with the model in the same way they would a patient. A design that has easier access to replace bone marrow fluid and the section of the proximal humerus would score higher. Ease of use is weighted at a 15 because it is important that the user experience is simplified as much as possible.

Durability: Durability refers to the expected life of the model, taking into account chosen materials and how replaceable components interact with the rest of the model. A simple design for the replaceable parts that limits wear and tear on the surrounding surfaces is desired so that the non replaceable components will last for a period of 5 years. Durability is weighted at a 15 because it is important that the design maximizes the lifecycle of the product.

Bone Marrow Access: Bone marrow access refers to how easily the client is able to refill the model with bone marrow between each procedure. This includes difficulty in placing the bone marrow within, as well as if the replaceable part would cause any leakage of the bone marrow. Bone marrow access is weighted at a 15 because making sure the user can easily fill and can extract bone marrow is crucial to the functionality of the model.

Cost: Cost refers to how much the replaceable component will cost based on the size of the 3-D printed piece repeatedly replaced and if there are any additional costs for supplemental materials that are needed to secure the replaceable component to the model. A model that requires less material will cost less and be scored higher in this category. Cost is weighted at a 10 because it is important that the material cost of replacement components are minimized.

Safety: Safety refers to the security and stability of the replaceable component within the model. It is important that the component stay seated within the non-replaceable bone component so that it does not interfere with the aspiration process. A replaceable component that does not come out of the model with the needle or fracture upon pressure and break into potentially harmful pieces of plastic would be rated higher. Safety is weighted at a 5 because the safety risks of performing the procedure should be similar to that of performing the procedure on a live animal.

Component Design Matrix Summary:

The slide method scored highest in the categories of joint interference, ease of fabrication, ease of use, durability, and cost. It scored the highest in the joint inference category because the slide piece is only affecting the aspiration site, while the other two models would attach to the joint and would interfere with the joint when replacing the piece. As for ease of fabrication the slide method scored the highest because it is considerably much smaller, and could be replicated easily on any printer. The size factor of this method also makes it easier to replace, and reduces the cost significantly compared to the other methods.

The screw method scored the second highest because it has the best bone marrow access with a port just inside the screw on the “cap” of the bone. This is very crucial for the project as the bone marrow element is what makes this model such an effective teacher, however while the screw cavity is helpful in this way, it interferes heavily with the shoulder joint as the entire top of the bone would have to be replaceable. Additionally with such a large replacement piece it would be quite costly and time consuming to replace, and with the thread required it would require high levels of accuracy affecting its ease of fabrication as well. While this is a hindrance the large surface area of this piece really expands the target area and would prevent the model from getting regularly damaged, and would keep the needle from slipping into these damaged spots, giving it a higher score in safety than the others. It is also less durable than the slide method because the thread will get chewed up over time.

The Velcro method scored the lowest overall for many reasons. Primarily it was the least safe option, as there is worry that the velcro would not be strong enough when students use the model, and when the needle is pulled out of the aspiration site the velcro could give and the whole bone piece could potentially come off. Additionally it would interfere heavily with the joint because it stretches almost to the top of the bone. The velcro also makes it slightly more costly to replace, and makes the piece itself less durable as the velcro would get weaker and weaker over time. This could also impact the security of the bone marrow fluid within the bone and could lead to movement of the internal components.