ENGINEERING

McMaster University

Design Project 2 – Investigating Hip Arthroplasty and Conceptual Design

IBEHS 1P10 – Health Solutions Design Projects

Tutorial 05

Team 30

Eli Taylor (tayloe26)

Mihnea Balan (balanm2)

Marc Gonsalves (gonsam2)

Ethan Meng (menge1)

Submitted: December 8, 2021

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Academic Integrity Statement

The student is responsible for performing the required work in an honest manner, without plagiarism and cheating. Submitting this work with my name and student number is a statement and understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University.

Elias Taylor 400388518

Elias Taylor

The student is responsible for performing the required work in an honest manner, without plagiarism and cheating. Submitting this work with my name and student number is a statement and understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University.

Marc Gonsalves 400383159

Marc Gonsalves

The student is responsible for performing the required work in an honest manner, without plagiarism and cheating. Submitting this work with my name and student number is a statement and understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University.

Mihnea Balan 400378197

x Mihnea Balan

The student is responsible for performing the required work in an honest manner, without plagiarism and cheating. Submitting this work with my name and student number is a statement and understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University.

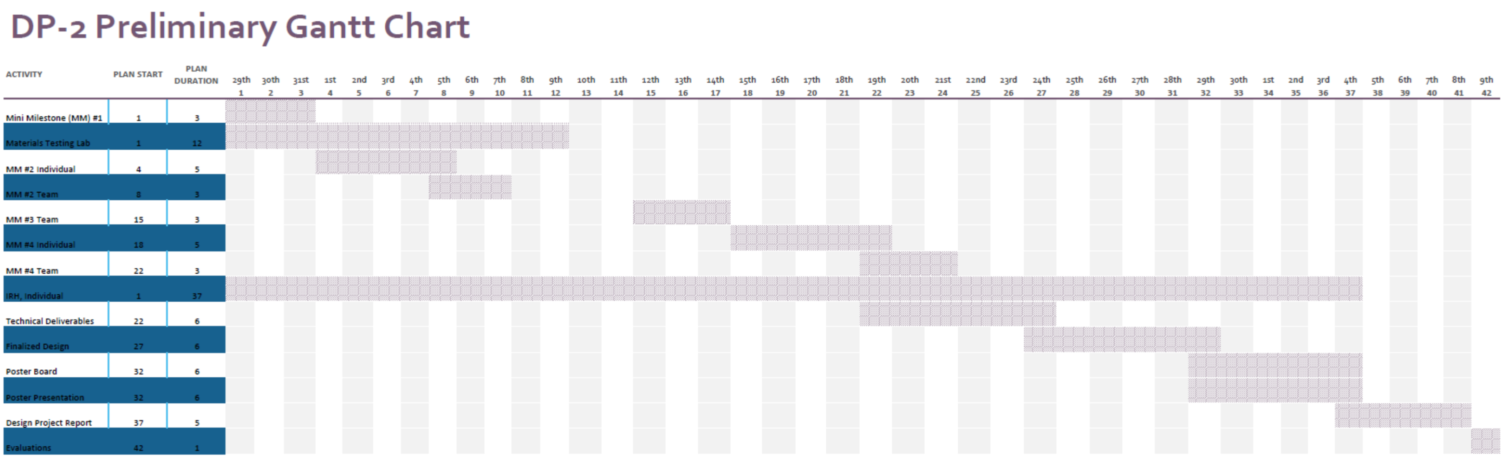
Ethan Meng Click or tap here to enter text.400382390

Ethan Meng

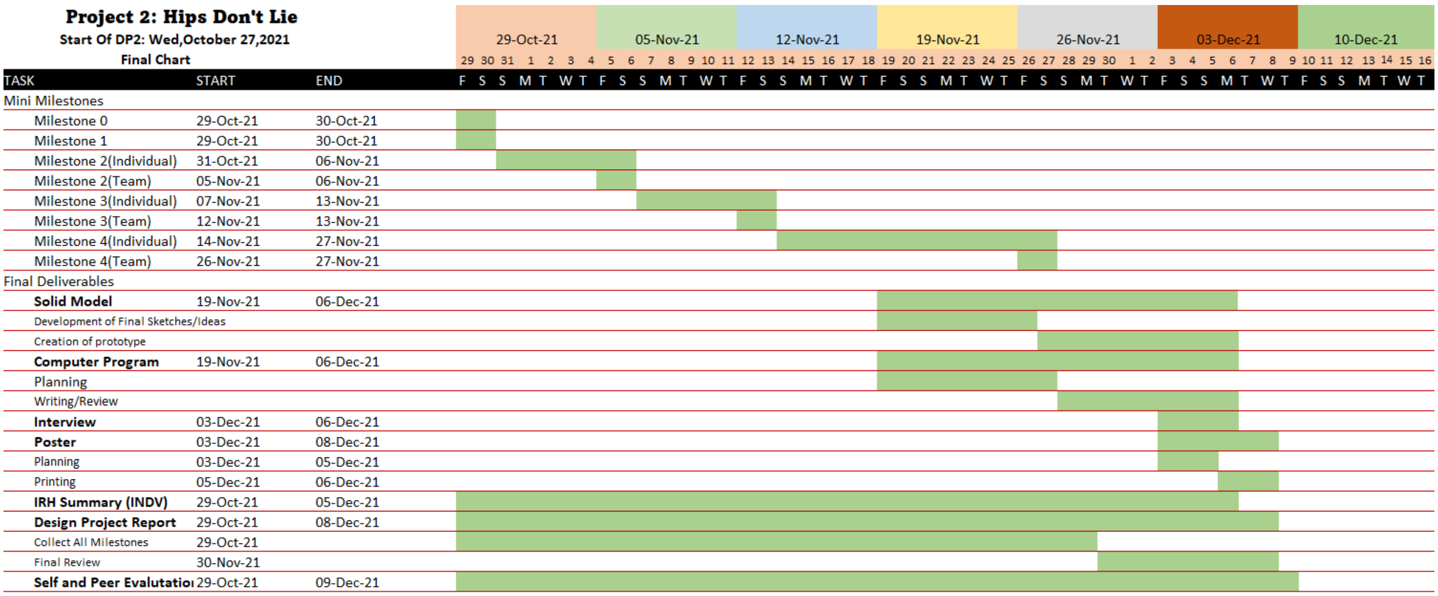
Main Body

Project Schedule:

Preliminary Gantt Chart:



Final Gantt Chart:



Scheduled Weekly Meetings:

Weekly Design Studio Agendas and Meeting Minutes:

Agenda Items | WK-8

- Quick recap of Need Statement/Objectives/Constraints and what is wrong with our patient
- Quick summary of the brainstorming and general shape of drawing each team member did for MM2
  - Eli
  - Mihnea
  - Marc
  - Ethan
- Let team members address the TA with any questions regarding their research
- Sketches:
  - Does detail make a sketch better?
  - Is it bad to include too much information?
- Gantt Chart:
  - Based on experience is this reasonable?
  - How rigidly do we have to follow our first chart?
- Questions/instructions/feedback from the TA
- What are we coding for?

Meeting Minutes

- ☺ Started working on giving advice on sketches (1:00)
- ☺ Sketches that are too cluttered can affect the perception of the sketch
- ☺ Signatures need to be included in a sketch, so remember to add signature
- ☺ Final submissions always the submission that is marked
- ☺ Use fiber as support in sketch
- ☺ Research further on fibrin
- ☺ Drawing Implant: Socket attached to hip through fibrin, a ball is attached to the socket to improve movement as a dual mobility system, another piece is connected to the femur bone to follow adjustments to the height of the legs (femoral stem).
- ☺ Computing team makes a program that allows the input of user weight with the output of the stress from weight (amount of material use)
- ☺ Fibrous encapsulation may make electronics difficult to use within the body (stops electronic signals) (e.g. pacemakers need good signal strength)
- ☺ Cement material as buffer of implant against bone (cement is made of Polymethyl Methacrylate)
- ☺ Titanium is good option for metal in implant (body will not attack)
- ☺ Polyethylene femoral neck

Agenda Items | WK-9

- Quick recap of Need Statement/Objectives/Constraints and what is wrong with our patient
- Quick overview of our final drawing design
- Let team members address the TA with any questions regarding any individual research, Order:
  - Eli
  - Mihnea
  - Marc
  - Ethan
- Does material choice matter/how does it affect our design?
- What is our short-term solution? What is our long-term solution?

- What information should we start to include on the final poster?

Meeting Minutes

- ☺ Work together on 3 calculations (fracture risk, fatigue life, reduced bone stress)
- ☺ Canadian Joint Replacement Registry (stats on hip replacements, may help in constructing poster)
- ☺ Materials do matter on design (needs to satisfy demands)
- ☺ Height matters for materials (resin probably won't work)
- ☺ Materials matter more for long term
- ☺ Problem definition section (diagnosis) on poster ~2/5 of poster
- ☺ Given poster boards

Agenda Items | WK-10

- Quick recap of Need Statement/Objectives/Constraints and what is wrong with our patient
- Let team members address the TA with any questions regarding any individual research, Order:
  - Eli
  - Mihnea
  - Marc
  - Ethan
- What might be the best way to spend this time?
- Is the mark breakdown for DP2 on A2L?
- How do we apply what we've been learning in lecture?
- Is it time to starting Coding/CADing, where do we find guidelines?

Meeting Minutes

- ☺ It is time to start coding/CADing
- ☺ IRH 2 due December 5th, 10% of DP2
- ☺ Best way to spend the time is probably to start on coding and CADing
- ☺ Push out poster last (but don't cram everything into next 2 weeks)
- ☺ Take concepts learned in class (e.g. material properties) and discuss it through justification in poster
- ☺ Learn assemblies later (don't use assemblies)
- ☺ CAD each component individual, use exploded view to show how parts fit in the implant
- ☺ Assemblies put several parts in same file, can use constraints
- ☺ Coding – use DP2 milestone guide

Agenda Items | WK-11

- Quick recap of Need Statement/Objectives/Constraints and what is wrong with our patient
- Let team members address the TA with any questions regarding any individual research, Order:
  - Eli
  - Mihnea
  - Marc
  - Ethan
- What material do you think is best out of ours? If that's too much, what should we use to decide?
- Should we get the poster board ASAP?
- How do we work on a physical poster board as a team?
- What might the presentations be like?
- Are the coding and CAD objectives now to be completed on our own time?

Meeting Minutes

- ☺ Picked materials on acetabular cup
- ☺ B-SiAlON ceramics
- ☺ Carbon-Fibre Reinforced Polybutylene Terephthalate (CFRPBT)
- ☺ Promotes bone regrowth (hydroxyapatite coating)
- ☺ Porous tantalum (Avoid stress shielding, better ware rates than titanium, good for avoiding dislocation, anti-bacterial, already commercially done, proven to work)
- ☺ HDHA-10/20/30 (Less bone degradation)
- ☺ Cobalt chromium molybdenum alloy (Can use coating to avoid toxic cobalt ions)
- ☺ Get poster board N O W
- ☺ Put pictures on poster, take up a bit of space (easier to look at picture, and listen to what you are saying)
- ☺ Too much text = distracting
- ☺ Categorized (lots of subtitles)
- ☺ Top left – introduction, bottom right – summary, fill other boxes with diagnostics, materials, etc.
- ☺ Citations at bottom corner (3-4 citations good)
- ☺ Not crammed
- ☺ Keywords are highlighted
- ☺ Simple colours, pick colours that work (coolors.co)
- ☺ Logo on top
- ☺ Creative titles
- ☺ Print with colour
- ☺ Work on presentation poster with PowerPoint
- ☺ Judges during the presentation
- ☺ Coding and CAD = own time
- ☺ Cup really thin, ball park it

Agenda Items | WK-12

- Quick recap of Need Statement/Objectives/Constraints and what is wrong with our patient
- Let team members address the TA with any questions regarding any individual research, Order:
  - Eli
  - Mihnea
  - Marc
  - Ethan
- How should we spend our time?
- Where's the poster board located? Do we designate one "poster person"?
- Which value do we use for elastic modulus, the one we decided upon?
- Will all design studies be in person next term?
- Any advice for the interviews?

Design Studio Worksheets:

Milestone 0:

MILESTONE 0 – COVER PAGE

Team Number: 30

Please list full names and MacID's of all *present* Team Members.

Full Name:	MacID:
Ethan Meng	menge1
Eli Taylor	tayloe26
Mihnea Balan	balanm2
Marc Gonsalves	gonsam2

Please attach your Team Portrait in the dialog box below.

MILESTONE 0 – TEAM CHARTER

Team Number: 30

Incoming Personnel Administrative Portfolio:

Prior to identifying Leads, identify each team members incoming experience with various **Project Leads**

	Team Member Name:	Project Leads
1.	Ethan Meng	☐M ☒A1 ☐A2 ☐C
2.	Eli Taylor	☐M ☐A1 ☐A2 ☒C
3.	Mihnea Balan	☒M ☐A1 ☐A2 ☐C
4.	Marc Gonsalves	☒M ☐A1 ☐A2 ☐C
		☐M ☐A1 ☐A2 ☐C

To 'check' each box in the Project Leads column, you must have this document open in the Microsoft Word Desktop App (not the browser and not MS Teams)

Project Leads:

Identify team member details (Name and MACID) in the space below.

Role:	Team Member Name:	MacID
Manager	Eli Taylor	tayloe26
Administrator 1	Mihnea Balan	balanm2
Administrator 2	Marc Gonsalves	gonsam2
Coordinator	Ethan Meng	menge1

MILESTONE 0 – TEAM CHARTER

Team Number: 30

Project Sub-Teams:

Identify team member details (Name and MACID) in the space below.

Sub-team:	Team Member Name:	MacID
Computing	Eli Taylor	tayloe26
	Marc Gonsalves	gonsam2
Modelling	Mihnea Balan	balanm2
	Ethan Meng	menge1

*For a team of 5, we **strongly** recommend **3 students be placed on the computation sub-team**

Milestone 1:

MILESTONE 1 – COVER PAGE

Team Number: 30

Please list full names and MacID's of all *present* Team Members.

Full Name:	MacID:
Marc Gonsalves	gonsam2
Ethan Meng	menge1
Eli Taylor	tayloe26
Mihnea Balan	balanm2

MILESTONE 1 – NEED STATEMENT

Team Number: 30

Need Statement

Write your Need Statement in the space below. Recall that your need statement should:

→ Have a clearly defined problem (*what* is the need?)
→ Indicate your end-user (*who* has the need?)
→ Have a clearly defined outcome (*what* do you hope to solve and *why* is it important?)

NEED STATEMENT:	Design a hip implant that will increase Jackie Chiles' limited range of motion as well as reduce the pain associated with his osteoarthritis and degenerative changes secondary to Perthes' disease. This implant should allow him to walk for an extended period of time without significant discomfort, thus improving his quality of life by eliminating his greatest day-to-day struggle.

MILESTONE 1 – PATIENT DIAGNOSIS

Team Number: 30

1. Document all pertinent information related to your assigned patient in order to create a **PATIENT PROFILE**.

SYMPTOMS:	- Hip pain (persistent in left hip, occasional temporary pain in right) - Severe limp, increased load on right leg - Can only walk for around two minutes before succumbing to the pain - Limited range of motion in left hip compared to right
IMAGING INDICATORS:	- Massive loss of cartilage in left hip joint - Abnormal growth of bone tissue in left hit joint - Extreme sclerosis in left hip joint
PREVIOUS MEDICATIONS / DOCTOR VISITS:	- Patient took 100 mg of Tramadol per day, but was ineffective - Currently on 2.5 mg of Oxycodone per day - Underwent physiotherapy designed to improve range of motion under non-load bearing exercises such as swimming
MISCELLANEOUS NOTES:	- Walks with a cane - Prostate cancer solved with prostatectomy o Did not undergo chemo or radiation therapy - Left leg is 1 cm shorter than the right - Pain is rated at 7 to 9 on a range of 10 - Not an active individual

2. Record your final diagnosis in the space below.

FINAL DIAGNOSIS:	- Legg-Calve-Perthes' Disease o Symptom onset started during childhood at age of 10 - Primary diagnosis compounded by osteoarthritis, development of a large osteophyte in the left hip, as well as coxa magna (deformity of the left femoral head)

*You must verify that your diagnosis is correct before you leave – we have

Milestone 2:

MILESTONE 2 – COVER PAGE

Team Number: 30

Please list full names and MacID's of all *present* Team Members

Full Name:	MacID:
Eli Taylor	tayloe26
Marc Gonsalves	gonsam2
Mihnea Balan	balanm2
Ethan Meng	menge1

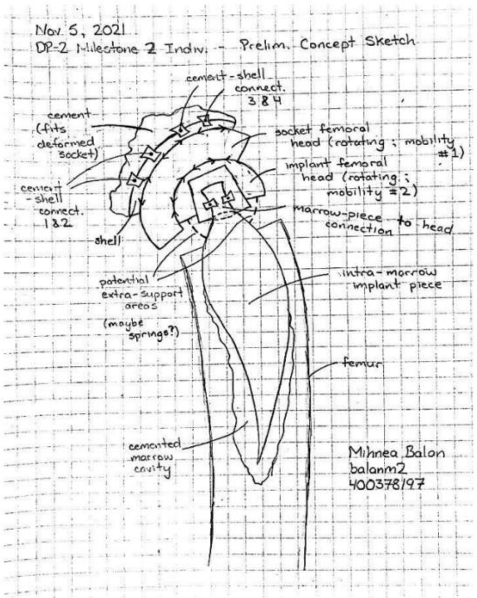
MILESTONE 2 – PRELIMINARY CONCEPT SKETCH

Team Number: 30

Name: Mihnea Balan | MacID: balanm2

Insert screenshot(s) of your refined sketches below

- *Cemented into both hip socket and femur for best fit (very important given socket deformation)*
- *Dual-mobility (two rotating "heads") for best range of motion + studies show low dislocation rate*
- *Shell-to-cement connection rather than shell-to-bone due to damage already done to bone*



Your Name:	Ethan Meng	**Colleague's Name:**	Mihnea Balan
Your MacID:	menge1	**Colleague's MacID:**	balanm2

Design Feedback:

Grid paper really helped to further indicate the size of the implant. I like the usage of cement to attach the deformed socket, to provide further support. The idea of springs could be expanded on a bit, but overall, the ideas are very interesting, and can be incorporated into a group design.

MILESTONE 2 – PRELIMINARY CONCEPT SKETCH

Team Number: 30

You should have already completed this task individually prior to Design Studio 8.

1. Copy-and-paste each team member's preliminary concept sketches on the following pages (1 sketch per page)
   → Be sure to indicate each team member's Name and MacID
   → If you are a team of 3, the last page of the worksheet may be left blank

We are asking that you submit your work on both worksheets. It does seem redundant, but there are valid reasons for this:

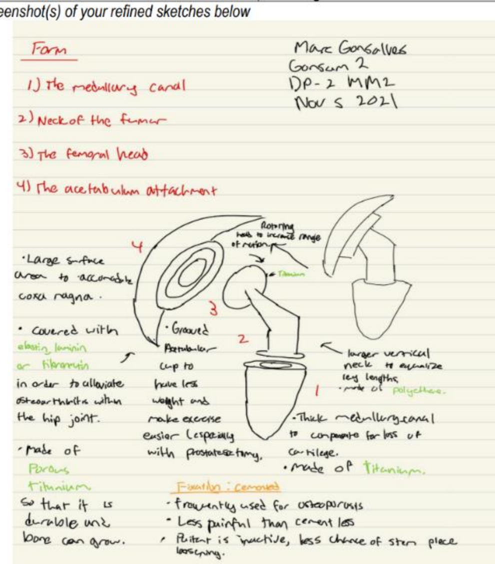
- Each team member needs to submit their preliminary concept sketches with the **Milestone Two Individual Worksheets** document so that it can be ***graded***
- Compiling your individual work into this **Milestone Two Team Worksheets** document allows you to readily access your team member's work
  - This will be especially helpful when completing ***Stage 2*** of the Milestone

MILESTONE 2 – PRELIMINARY CONCEPT SKETCH

Team Number: 30

Name: Marc Gonsalves | MacID: gonsam2

Insert screenshot(s) of your refined sketches below



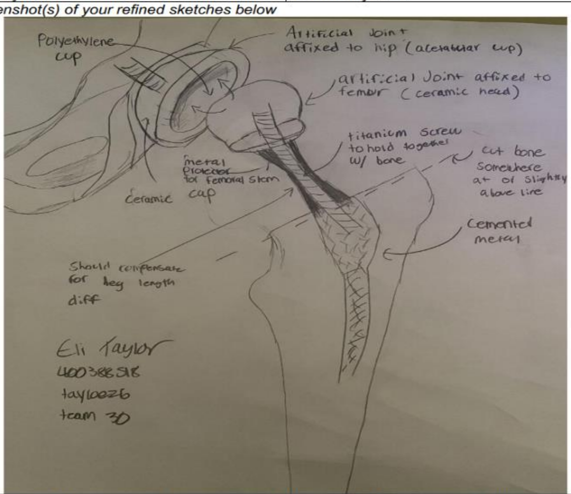
Your Name:	Mihnea Balan	**Colleague's Name:**	Marc Gonsalves
Your MacID:	balanm2	**Colleague's MacID:**	gonsam2

Design Feedback:

- Good idea to split sketch into several components, makes it easier to understand the purpose of each part along with a short description of their functions
- Assigning specific characteristics to the different parts in order to address corresponding patient issues is a very practical approach (i.e., protein coating to alleviate osteoarthritis)
- Looking for materials and coatings ahead of time will help in preparing future iterations
- More detail in actual sketch would help with understanding the assembly of various parts

Name: Eli Taylor	MacID: tayloe26

Insert screenshot(s) of your refined sketches below



Your Name:	Marc Gonsalves	**Colleague's Name:**	Eli Taylor
Your MacID:	gonsam2	**Colleague's MacID:**	tayloe26

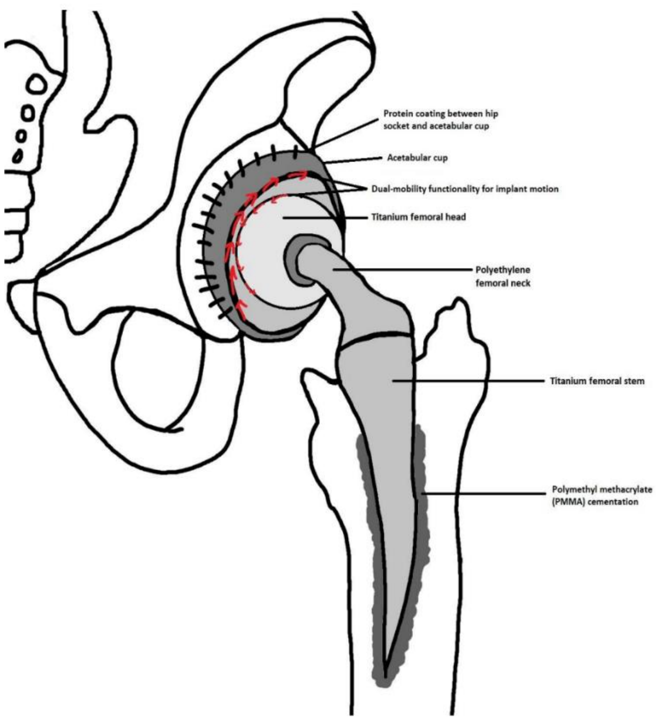
Design Feedback:

- Sketch is clear and easy to understand
- Effective use of labels
- Good use of dotted lines to show the procedure for the bone cutting
- Good attention to detail with the metal coating idea
- Arrows are properly used to demonstrate design
- Not cluttered, simple
- Design seems to be effective

MILESTONE 2 – REFINED CONCEPT SKETCH

Team Number:	30

1. Complete your refined sketch on a separate sheet of paper
2. Take a photo of your sketch
3. Insert your photo as a Picture (Insert > Picture > This Device)
4. **Do not include more than one sketch per page**

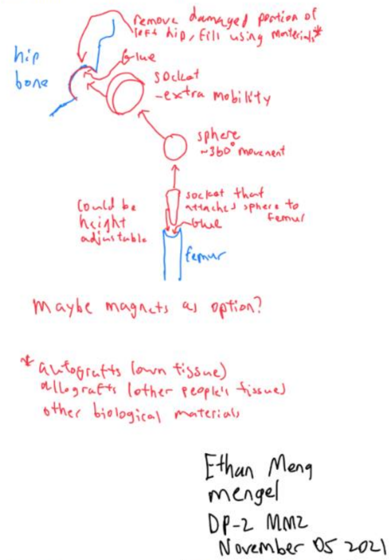


MILESTONE 2 – PRELIMINARY CONCEPT SKETCH

Team Number:	30

Name: Ethan Meng	MacID: menge1

Insert screenshot(s) of your refined sketches below



Your Name:	Eli Taylor	**Colleague's Name:**	Ethan Meng
Your MacID:	tayloe26	**Colleague's MacID:**	menge1

Design Feedback:

- Good ideas with autografts and allografts
- Use of magnets could be elaborated on, hard to picture
- Usage of glue is a unique idea
- Two-piece system which fixes both the hip joint and femur bone problems
- The drawing is relatively simplistic for the ideas presented; color makes it somewhat harder to follow

MILESTONE 2 – GROUP DISCUSSION

Team Number:	30

Discuss the advantages and disadvantages of your refined concept solution

Advantages:

- Increases range of motion and general mobility
- Use of cement provides support towards femur bone structure as the femur on the affected side is thinner
- Fixes height difference between legs (alignment issues)
- Materials are long lasting and are a one-time solution
- Dual-mobility hip implants are less susceptible to dislocation (motion is spread between two rotating sections in femoral head rather than one)

Disadvantages:

- Complexity of structure, many parts needed to assemble implant
- Removing a large percentage of bone (thin femur) to insert the hip implant
- Expensive materials (protein coatings, titanium, etc.)

Discuss the extent to which your refined concept solution addresses the need statement

Our design solution drastically improves Jackie Chiles' range of motion by using a dual-mobility hip implant, which is also resistant to dislocation by spreading rotation of the femoral head between two sections (hence, "dual-mobility"). His discomfort from osteoarthritis is also reduced by a protein coating (i.e., elastin, laminin, fibrin, etc.) on the acetabular cup that lies between the hip socket and the femoral head. The reduction in pain and increase in mobility as a result of our hip implant will ultimately increase his quality of life by eliminating his pre-existing daily struggles.

Milestone 3:

MILESTONE 3 – COVER PAGE

Team Number: 30

Please list full names and MacID's of all *present* Team Members.

Full Name:	MacID:
Marc Gonsalves	gonsam2
Eli Taylor	tayloe26
Mihnea Balan	balanm2
Ethan Meng	menge1

Any student that is ***not*** present for Design Studio will not be given credit for completion of the worksheet and may be subject to a 10% deduction to their DP-2 grade.

MILESTONE 3 (STAGE 2) – PRELIMINARY DESIGN ANALYSIS
FATIGUE LIFE

Team Number: 30

Calculate the fatigue life of your assigned material.

→ Show all of your work neatly and in detail (do not skip steps), include the correct number of significant digits, and correct units

2) Fatigue life (titanium):

$$\sigma_{amp} = \frac{\sigma_{max} - \sigma_{min}}{2}$$

$$= \frac{\sigma_{max} + \sigma_{max}}{2} \rightarrow = \frac{\cancel{2}\,\sigma_{max}}{\cancel{2}}$$

$$\sigma_{max} = \sigma_A \cdot \frac{30}{3.5}$$

$$= 62.62 \cdot \frac{30}{3.5}$$

$$= 536.74 \text{ MPa}$$

$$\boxed{= 537 \text{ MPa}}$$

judging by S-N curve of Ti-5AI-4V,

$\boxed{N \sim 1000 \text{ or } 10^3 \text{ cycles}}$

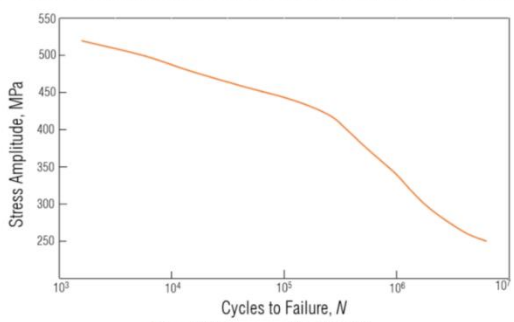


Figure 1. S-N curve used for Ti-5Al-4V

For completing Question 2, use the following **maximum cyclical load** values: + BW•30 N and – BW•30 N

MILESTONE 3 (STAGE 2) – PRELIMINARY DESIGN ANALYSIS
FRACTURE RISK

Team Number: 30

Calculate the fracture risk of the implant stem assuming a combined loading scenario. Don't forget to:

→ Compare tensile stress on the lateral side of the implant to the ultimate tensile strength of your assigned material

→ Show all of your work neatly and in detail (do not skip steps), include the correct number of significant digits, and correct units

Jackie Chiles : $m = 103.5$ kg

→ $D_o = 33$ mm

→ $D_i = 17$ mm

→ $L = 54$ mm

1) Fracture risk : medial is larger than lateral

$$FR = \frac{\sigma_{total}}{UTS_{impl.}} = \frac{\overbrace{\sigma_A + \sigma_B}}{UTS_{Titanium}}$$

① $$\sigma_A = \frac{F}{A} = \frac{3.5\,mg}{\frac{\pi}{4}d^2} = \frac{3.5 \cdot 103.5 \cdot 9.81}{\frac{\pi}{4}\left(\frac{17}{2}\right)^2}$$

$$= 62.62 \text{ MPa}$$

② $$\sigma_B = \frac{My}{I} = \frac{F \cdot L \cdot \frac{1}{2}d}{\frac{\pi}{64}d^4} = \frac{3.5 \cdot 103.5 \cdot 9.81 \cdot 54 \cdot \frac{17}{4}}{\frac{\pi}{64}\left(\frac{17}{2}\right)^4}$$

$$= 3182.84 \text{ MPa}$$

medial $$FR = \frac{62.62 + 3182.84}{950}$$

$$\boxed{= 3.42 \longrightarrow 342\,\%\text{ risk}}$$ * FAKE VALUE; WRONG NUMBERS

lateral $$FR = \frac{3182.84 - 62.62}{950}$$

$$\boxed{= 3.28 \longrightarrow 328\%\text{ risk}}$$ * FAKE VALUE; WRONG NUMBERS

MILESTONE 3 (STAGE 2) – PRELIMINARY DESIGN ANALYSIS
BONE STRESS REDUCTION

Team Number: 30

Calculate the magnitude of bone stress reduction after implant reconstruction. Don't forget:

→ Calculations should not consider a combined loading scenario, like in Part 1 of this Milestone

→ Show all of your work neatly and in detail (do not skip steps), include the correct number of significant digits, and correct units

3) Reduced bone stress :

$$\sigma_{reduc} = \sigma_{comp} \cdot \left(\frac{2 \cdot E_{bone}}{E_{bone} + E_{implant}}\right)^{\frac{1}{2}}$$

$$= \frac{F}{A}\sqrt{\frac{2E_{bone}}{E_{bone} + E_{impl.}}}$$

$$= \frac{30\,mg}{\frac{\pi}{4}(D_o^2 - D_i^2)}\sqrt{\frac{2E_{bone}}{E_{bone} + E_{impl.}}}$$

$$= \frac{30 \cdot 103.5 \cdot 9.81}{\frac{\pi}{4}(33^2 - 17^2)}\sqrt{\frac{2 \cdot 17000}{17000 + 114000}}$$

$$\boxed{\sigma_{reduc} = 24.7 \text{ MPa}}$$

Titanium Alloy (Ti-6Al-4V)

Table 1. Mechanical properties of tested material and cortical bone:

	Elastic Modulus (GPa)	Ultimate Strength (MPa)
Ti-6Al-4V	114	950
Cortical Bone	17	133

Milestone 4:

MILESTONE 4 – COVER PAGE

Team Number: 30

Please list full names and MacID's of all *present* Team Members

Full Name:	MacID:
Elias Taylor	tayloe26
Mihnea Balan	balanm2
Marc Gonsalves	gonsam2
Ethan Meng	menge1

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MILESTONE 4 – MATERIALS SELECTION GROUP DISCUSSION

Team Number: 30

Fill in the Materials Selection table below related to the **STRUCTURE** of the material by *copy-and-pasting* each team members individual research. Discuss your findings as a team.

→ Note: some columns include headers (to help get you started) and some are left blank
- Add additional column headers as you feel are appropriate
- You only have to fill in the columns you think are relevant

→ If a candidate material proposed in one of the other tables is not included below, you should add it to this table and fill out the appropriate fields as a *team*

Material	Structure					
	Class	Atomic Arrangement	Interatomic Bonding			
β–SiAlON	Ceramic	Crystalline (hexagonal rings arranged in layers; NOT a cubic crystalline structure)	The larger the nitrogen-to-oxygen ratio, the more covalent and directional the bonds become (Si-N bonds are covalent and Al-O bonds are ionic)			
Carbon-Fibre-Reinforced Polybutylene Terephthalate (CFRPBT)	Polymer	Amorphous (PBT is a semi-crystalline thermoplastic and carbon fibres are a group of materials that can be either be amorphous, semi-crystalline, or crystalline. Carbon fibre percentage can range from 3-50% with common utilization in the 30% range)	PBT bonds are covalent bonds and carbon fibre bonds are non-polar covalent bonds, the two materials are also held together through covalent bonds.			
Porous Tantalum	Metal	Crystalline (alpha- and beta-phases; alpha is more common and has a more defined crystal lattice)	Ionic, as it is metallic (depends on bond angle; angular- dependent)			
HDHA-10/20/30	Polymer	High % crystallinity (crystallinity and density tend to increase the more interatomic bonds are present)	Polyethylene component has covalent bonding, and there are also forces between the HDPE & HA			
Cobalt Chromium Molybdenum Alloy (CoCrMo)	Metal(alloy)	Crystal (cobalt rich alloys typically have a FCC structure while chromium rich alloy have a BCC crystal structure).	Mostly metallic bonding between cobalt, chromium and molybdenum within structure. Other elements may cause different bonding.			
Alumina Zirconia	Ceramic	Monocyclic crystal (zirconia changes shape from tetragonal after being exposed to alumina).	Ionic bonding (for example between oxygen and aluminium in alumina). Metallic bonding used to form overall structure.			

MILESTONE 4 – MATERIALS SELECTION GROUP DISCUSSION

Team Number: 30

Fill in the Materials Selection table below related to the **PROPERTIES** of the material by *copy-and-pasting* each team members individual research. Discuss your findings as a team.

→ Note: some columns include headers (to help get you started) and some are left blank
- Add additional column headers as you feel are appropriate
- You only have to fill in the columns you think are relevant

→ If a candidate material proposed in one of the other tables is not included below, you should add it to this table and fill out the appropriate fields as a *team*

Material	Properties					
	Elastic Modulus	Ultimate Strength	Toughness, Fracture	Wear	Corrosion Resistance	
β–SiAlON ceramics	288 GPa [1]	945 MPa [1]	- Hardness of 15 GPa [1] - Fracture toughness of 7.7Mpa$^{1/2}$ [1] - Brittle material	- Fragments of debris have low cytotoxicity [2] - Low wear debris volume [2] - High fracture toughness and hardness ensure "excellent wear resistance" [2]	B-SiAlON is usually coated in diamond-like carbon (DLC) films which are designed around high coverage and good strength as a corrosion barrier [3]	
Carbon-Fibre-Reinforced Polybutylene Terephthalate (CFRPBT)	4.70-40.0 GPa [6] (Depending on carbon fibre content)	45-220 MPa [6] (Depending on carbon fibre content)	- Fracture toughness of 2.753 Mpa$^{1/2}$ [6] - Hardness of 180 MPa - Ductile material	- Substance has demonstrated minimal toxicity as a particulate [7] - Studies demonstrated sufficient wear resistance in vivo [7]	Polybutylene terephthalate has excellent resistance factors to water, weak alkalis, weak acids, and good resistance factors against typical organic solvents [6]	
Porous Tantalum	3 GPa (in between the EM of cancellous and cortical bone)	Between 50-110 MPa, depending on porosity (around 10x stronger than femoral head)	90-150 MPa-(m)$^{1/2}$ (significantly higher than the fracture toughness of titanium)	10^{-4} mm^3 (Nm)$^{-1}$ (significantly better wear rate when compared to titanium)	High corrosion resistance, but is lowered by Cu (avoid use of this element)	
HDHA-10/20/30	340/390/450 MPa (ranging from ½ to 2/3 the value of UHMWPE; ultra-high molecular weight polyethylene)	38/42/48 MPa (comparable to UHMWPE; given ultimate strength of 40 MPa in comparison table)	Becomes lower as the mass % of HA increases ***numeric values unavailable; novel material	Testing shows that the wear quantity is negligible after 10000 cycles and is 1/3 less worn than UHMWPE at all loads and # of cycles	Corrosion-prone when crosslinked via gamma radiation ***more info unavailable; novel material	
Polycarbonate Urethane	Between 0.621-5.50 GPA	Average strength of 50.6 MPA	There is a 3 year survival rate of 0.841, which translates to a low fracture rate	Wear rate is low, as there is minimal loss of materials after testing	The material is a soft hydrophilic material that is resistant to hydrolysis, biodegration, and other reactions that could affect the build of the material, making the polymer very resistant to corrosion	
Calcium Hydroxyapatite	Between 7-13 GPA	Between 38-48 MPA	Fracture toughness of between 0.5-1 MPA	The substance has a wear rate of 1.6*10^-3 mm^3/Nm	Rp=65.85 kΩ/cm2; Icorr = 0.63 μA/cm2 ; Ecorr=−167 mV/ECS	
Cobalt Chromium Molybdenum Alloy(CoCrMo)	235-247 GPA for Co-28Cr-6Mo (approx 10 times higher than cortical bone)	Minimum 1192 MPA	The hardness ranges from 1155 MPA to 1290 MPA. Fracture toughness approximately 120 to 150 MPa^1/2	Extremely low wear rate due to hard carbides being embedded in a matrix.	Low corrosion due to the high reactivity of Co and Cr which forms a oxide layer of protection.	
Alumina Zirconia	251-375 GPA for dense alumina-containing tetragonal zirconia (80% zirconia)	Around 1138 MPa	Hardness of 14.5 GPA. Fracture toughness of 6MPa^1/2	The sintering process creates a very smooth microstructure which leads to a very low wear rate.	The structure of the material limits the transformation of zirconia composites, preventing corrosion from water and fluids.	

MILESTONE 4 – MATERIALS SELECTION GROUP DISCUSSION

Team Number: 30

You should have already completed **Stage 1** of Milestone 4 individually prior to Design Studio 10.

1. Copy-and-paste each team member's *Preliminary Materials Selection* research from the individual worksheets in the tables on the following pages
   → Between the 4-5 team members, all tables should include a minimum of 4 candidate materials
2. Recalling that each team member only needed to consider **TWO** of the three criteria (structure, properties, processing) for **Stage 1**, your team should now fill in any tables not completed for each unique candidate material
   → For example, if a team member proposed *cobalt chrome* and *titanium*, researching the **structure** and **properties** of each, the *team* should then research the **processing** of each of these materials, filling in the appropriate table.

Implant Component:	Acetabular Cup

We are asking that you submit your work on both *Individual* and *Team* worksheets. It does seem redundant, but there are valid reasons for this:
- Each team member needs to submit their preliminary materials selection with the **Milestone Four Individual Worksheets** document so that it can be ***graded***
- Compiling your individual work into the **Milestone Four Team Worksheets** document allows you to readily access your team member's work
  - This will be especially helpful when completing ***Stage 2*** of the Milestone

MILESTONE 4 – MATERIALS SELECTION GROUP DISCUSSION

Team Number: 30

Fill in the Materials Selection table below related to the **PROCESSING** of the material by *copy-and-pasting* each team members individual research. Discuss your findings as a team.

→ Note: some columns include headers (to help get you started) and some are left blank
  - Add additional column headers as you feel are appropriate
  - You only have to fill in the columns you think are relevant

→ If a candidate material proposed in one of the other tables is not included below, you should add it to this table and fill out the appropriate fields as a *team*

Material	**Processing**					
	Coatings	Drug Delivery Options	Corrosion Resistance			
β–SiAlON ceramics	Both (CrAlSi)N and DLC coatings can increase the wear resistance of the material by up to 1.5 times while also improving elastic modulus, wear resistance, and micro hardness [4], [5].	There are no feasible drug delivery options associated with this material.	**See Above**			
Carbon-Fibre-Reinforced Polybutylene Terephthalate (CFRPBT)	Hydroxyapatite coating allows for an increase in bone bonding, an increase in healing, and stimulates the growth of new tissues [7], [8].	Outside of an initial coating of antibiotics there remains no way to consistently provide drugs through the CFRPBT acetabular cup.	**See Above**			
Cobalt Chromium Molybdenum Alloy (CoCrMo)	Super lattice ceramic coating showed significantly lower level of ions within blood for SLC-MoM implants.	No drug delivery options for CoCrMo.	High wear and corrosion resistance. The high reactivity causes Co and Cr to quickly oxidize at the surface which forms an oxide layer. This layer precents the solution from coming in contact with the metal, which reduces corrosion.			
Alumina Zirconia	Fibronectin (mediates cell adhesion and improves implant attachment) .	No drug delivery options for fibronectin.	High wear and corrosion resistance. The structure of the material encases and limits the transformation of zirconia composites, which makes them more resistant to corrosion from water and fluids.			
Porous Tantalum	The osseointegrative properties of tantalum are very useful for orthopedic implants, so it is common to bolster them via hydroxyapatite coatings Tantalum is often considered as a coating material rather than requiring coating itself	Drug delivery options are limited to antimicrobial coatings such as PHAs (most often dip-coating) Small tantalum cylinders can also release antibiotics such as vancomycin for up to 2 weeks	Highly resistant to corrosion, so it is often used as an anti-corrosive coating rather than being treated to resist corrosion			
HDHA-10/20/30	Techniques such as nano-ceramic coating and the addition of carbon nanotubes could be implemented to improve general performance Natural oils are the optimal lubricant for polymers against metallic components	Little to no research is available because of the material's recency, but is assumed to have similar traits to UHMWPE: Electrostatic spray coating and chemical etching can allow drug delivery for several weeks	Corrosion resistance of HDPE is already high and is bolstered by increasing mass % of hydroxyapatite (HA), which is often used as an anti-corrosive coating			

MILESTONE 4 – PROPOSED MATERIAL

Team Number: 30

Proposed Material:	β-SiAlON

Explain why you selected this material based on the structure, properties and processing:

We selected β-SiAlON as our material for the acetabular cup because of the promise that silicon nitride (ceramic) shows in research relating to its biomedical applications. β-SiAlON is created through a specific manufacturing process of silicon nitride with Al and O ions (referred to as SSN) that further bolsters its biocompatible characteristics, such as osseoconductivity.

In addition, β-SiAlON is naturally corrosion- and wear-resistant, has a very high compressive strength that is important for an acetabular cup (as it is always pressed into the hip socket), and exhibits a significantly high fracture toughness for a ceramic – this somewhat offset the biggest drawback of ceramics: their brittle nature.

Comment on why the material selected makes the most sense ***for your patient***

β-SiAlON makes the most sense for use in our patient's acetabular cup due to its osseointegrative potential, its impressive tribological performance, and its remarkable compatibility with polyethylene (***likely choice material for the acetabular liner).

First, β-SiAlON exhibits high levels of cellular adhesion with osteocytes, similarly to materials that have been coated in hydroxyapatite. This will improve the chances of the acetabular cup to properly integrate with the acetabulum and is doubly important for our patient because of their significantly damaged hip socket, which increases the implant's risk of dislocation.

Next, available processing methods for β-SiAlON allow it to avoid an excessively high friction coefficient by tailoring its surface smoothness. In addition, the more load cycles β-SiAlON experiences, a lubricating silicon oxide film becomes more prevalent. This will limit possible frictional damage and further breakdown of the patient's deformed acetabulum.

Finally, aseptic loosening is a concerning risk for our patient due to their irregularly shaped hip socket, which may lead to fitting issues. Silicon nitride's surface can absorb oxygen from degrading polyethylene liners (most common liner used with Si_3N_4-based acetabular cups) into the β-SiAlON structure, decreasing wear debris from the liner to combat aseptic loosening.

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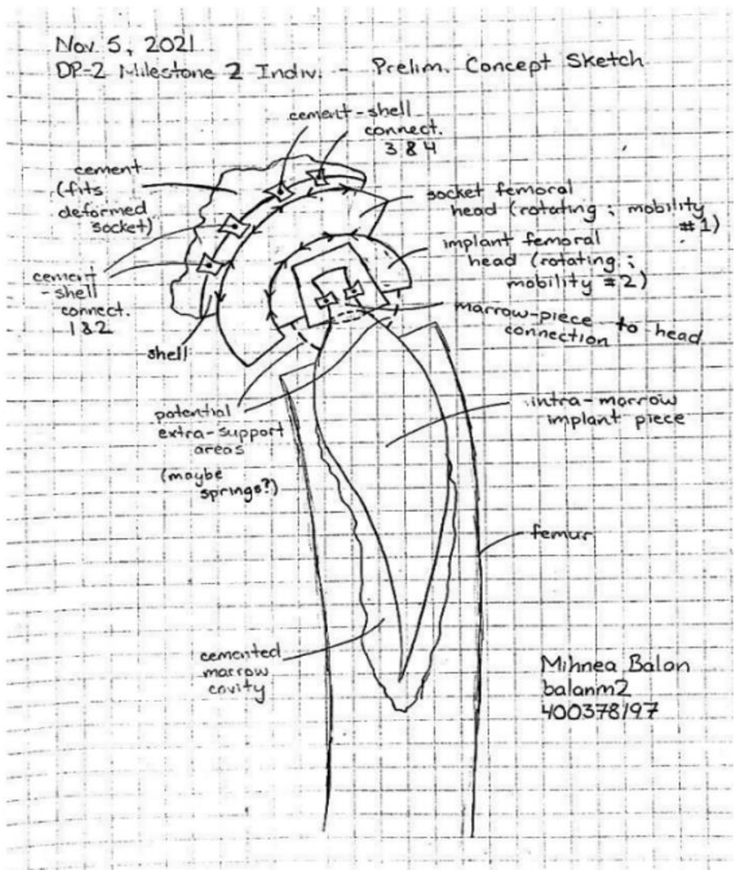
Appendices

*** Add relevant Appendices as instructed. A sample Appendix is shown below.**

Appendix A: Preliminary Sketching



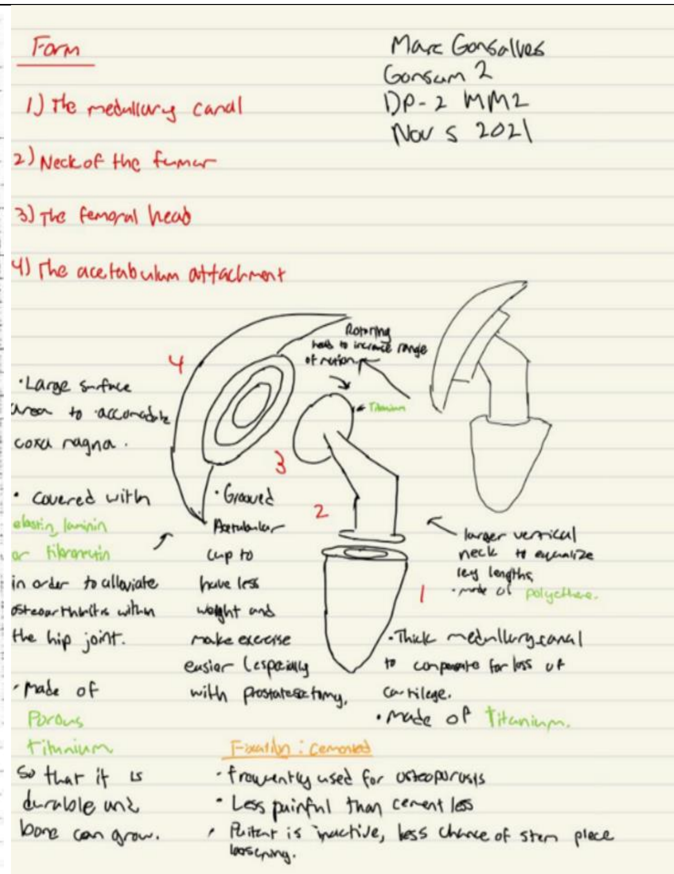
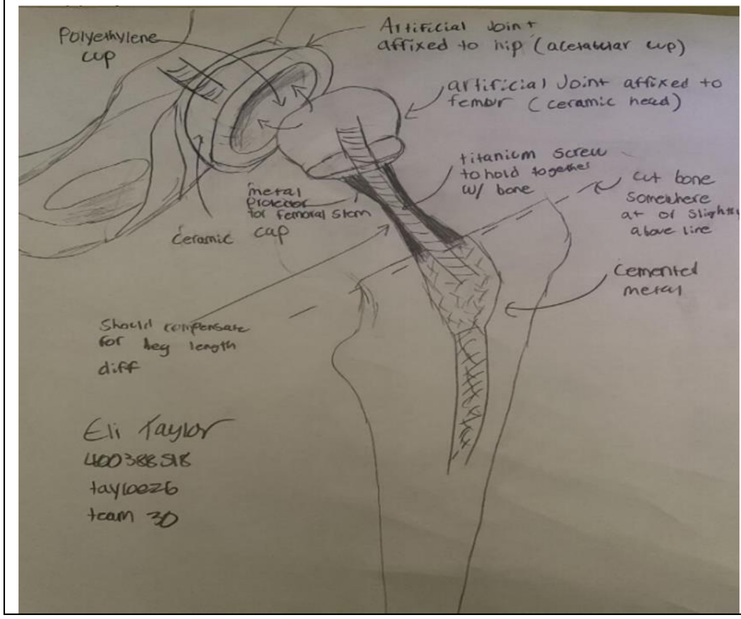


Figure 1: Mihnea's Individual Milestone 2 Sketch

Figure 2: Marc's Individual Milestone 2 Sketch



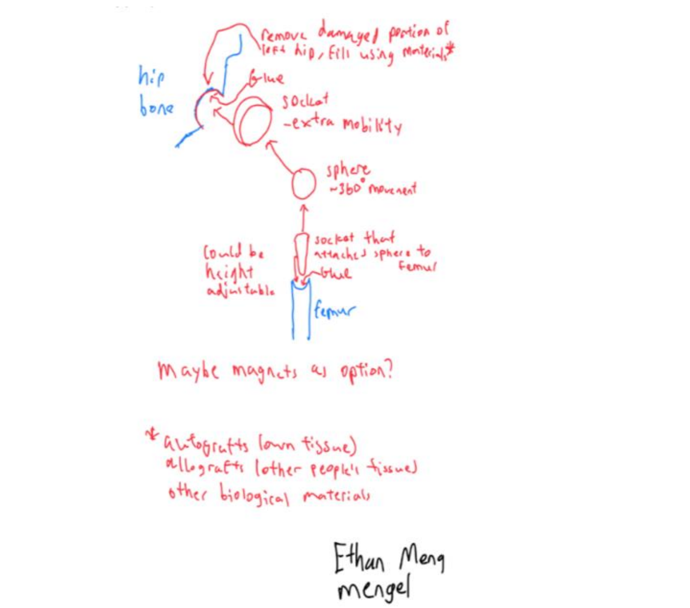


Figure 3: Eli's Individual Milestone 2 Sketch

Figure 4: Ethan's Individual Milestone 2 Sketch

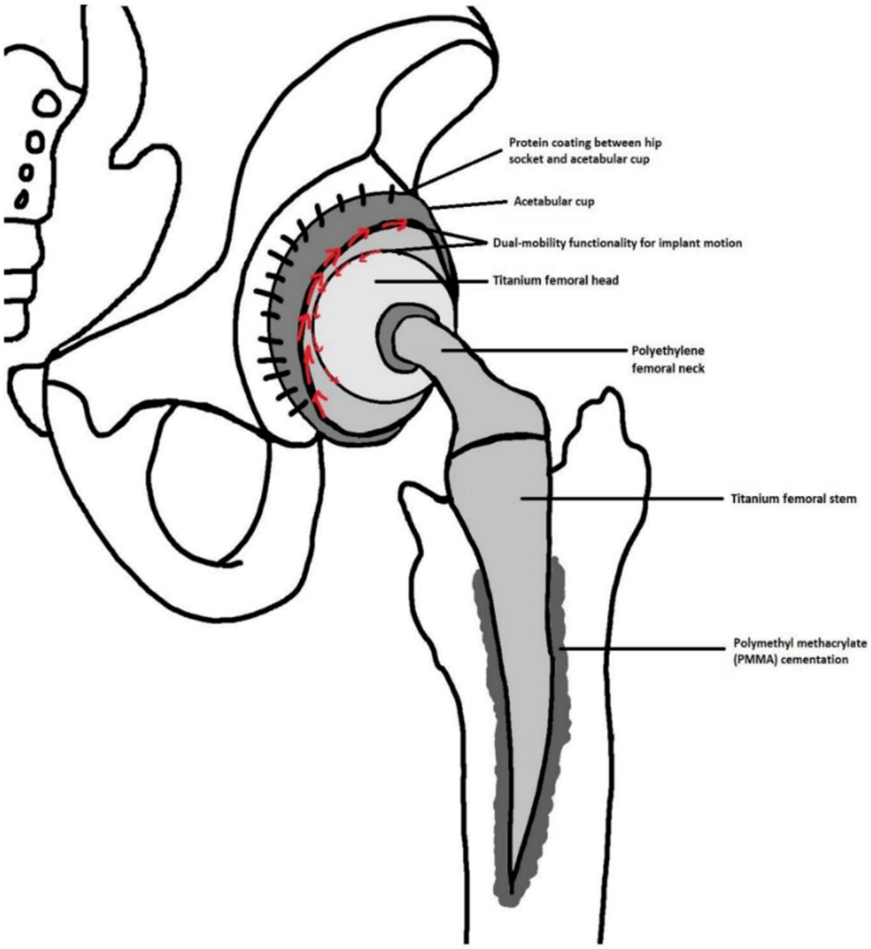


Figure 5: Team 30's Milestone 2 Concept

Appendix B: Preliminary Solid Modelling

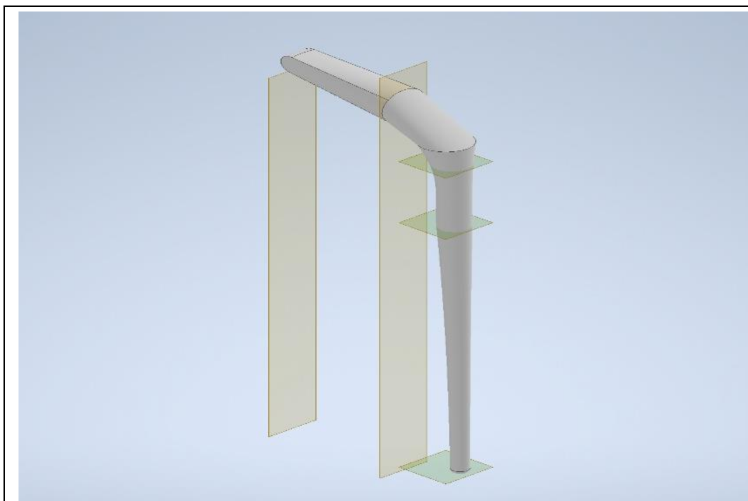


Figure 6: 1st Stem Iteration

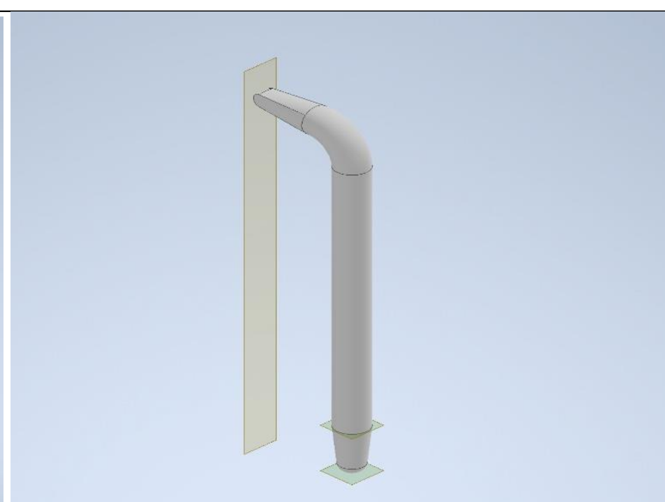


Figure 7: 2nd Stem Iteration

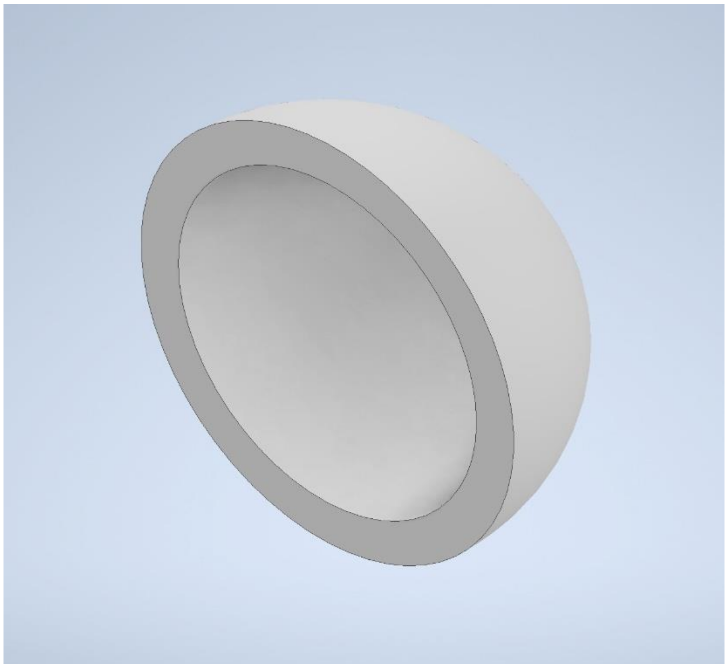


Figure 8: Acetabular Cup

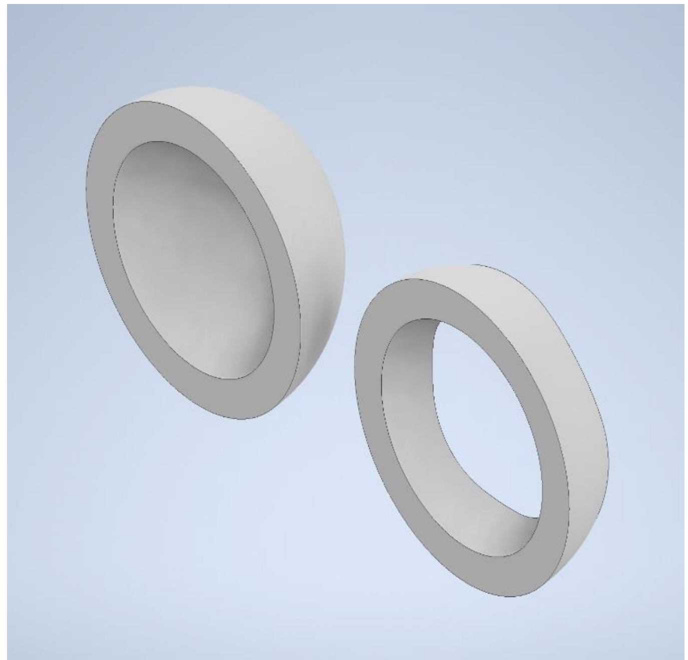


Figure 9: Acetabular Liner

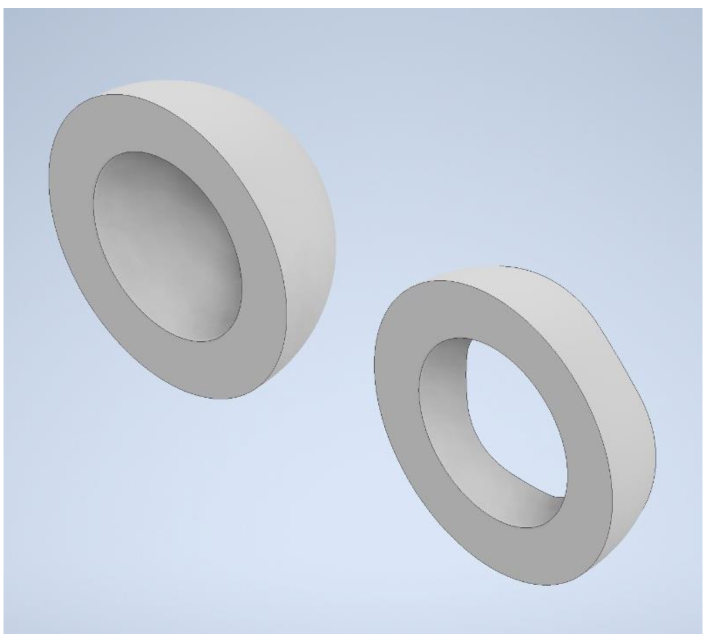


Figure 10: Outer Femoral Head

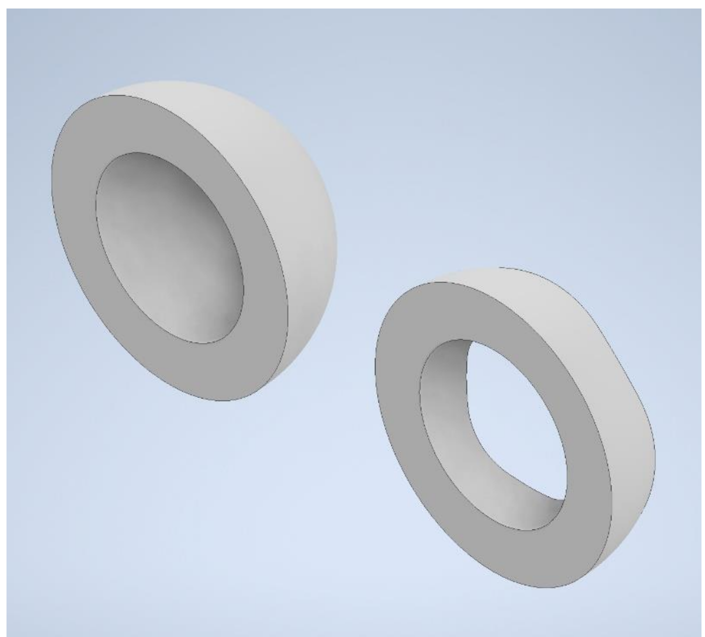


Figure 11: Inner Femoral Head

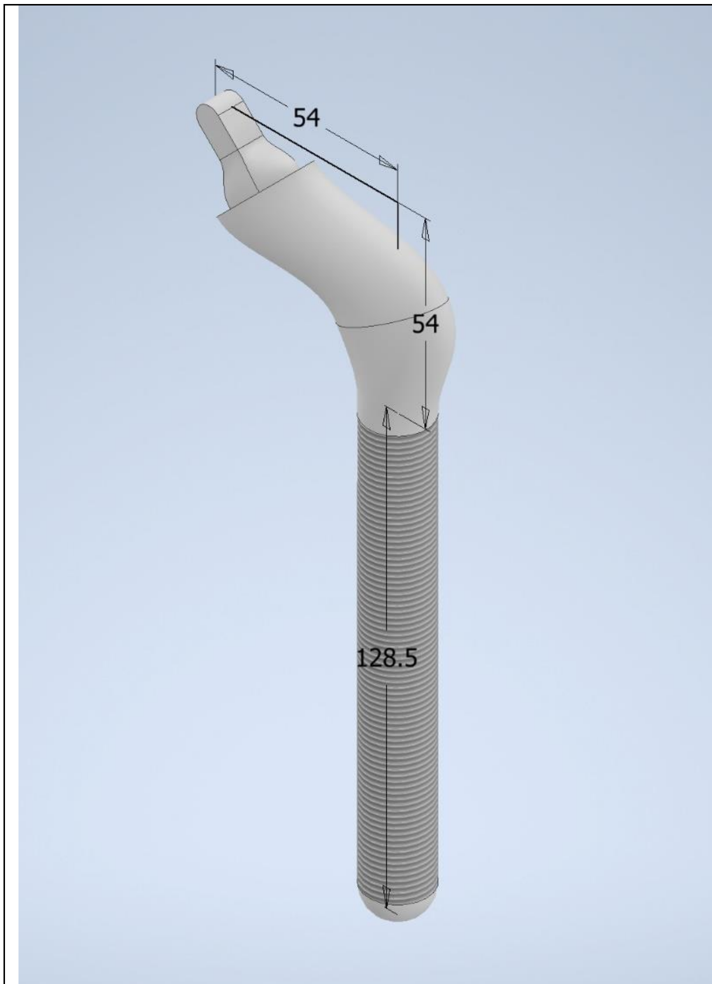


Figure 12: Final Stem Iteration

Figure 13: Assembled 3D-Printed Implant