Engineering Design and Graphics 1C03
McMaster Engineering 1

Instructor: Dr. Doyle
Last Updated: November 7, 2018

1. Essential Details

1.1 Team Formation:

This is a **team project**. Teams must have **three** members, unless a lab section enrolment is not evenly divisible by 3. In the case where a lab section enrolment cannot be evenly divisible by three, then two-member teams will be assigned. Team member names must be submitted to your lab IAI. Each team must obtain a team number for grading identification and online resources (ask your IAI for this is you do not have it!). Any student(s) not in a team will be assigned by the IAI. If necessary, IAIs will reassign students to make appropriate sized teams. Decisions of which students to reassign are based on when a team/student registered with the IAI for the project. All members must also register as a member of the team on Avenue to submit components and receive grades/feedback.

1.2 Submission Requirements:

This project will have a final submission of three components:
1) A technical design report
2) Software models, including solid/assembly modelling and dynamic simulation
3) Working physical assembly

In addition, the team will be interviewed (together and individually) on all aspects of the project. Every member is responsible for an in-depth understanding of all components of the project and may be examined as such. During the interview, teams will demonstrate their working physical assembly.

1.3 Milestones and Submission

There are five major milestones to be completed:
1) Timeline and team agreement (Milestone 0)
2) Preliminary design, timeline and (Milestone 1)
3) Physical printed gears (Milestone 2)
4) Final submission with interview
5) Peer review

Table 1: Important Dates

Description	Deadline
Milestone 0 – Timeline and agreement	October 19, 2018
Milestone 1 – Preliminary Design	October 29, 2018
Milestone 2 – 3D Printed Gears	November 19, 2018
Milestone 3 – Final Submission	Scheduled during final Lab times (see Avenue for your time/date)
Milestone 4 – Peer Review	December 7, 2018

Note the last date for EPIC printing is November 28, 2018.

2. Your Project: Design of a Hand Prosthesis

2.1 Overview

You have recently been hired by biomedical company 'BME Devices' and in a small team of engineers your first assignment is to develop a low-cost gripping apparatus as a proof-of-concept for an advanced prosthetic. A proof-of-concept design is common practice in industry for demonstrating the potential of an idea for real-world application before committing significant time and expense to developing a final design. The gripping apparatus is intended to act as a full-right-hand prosthesis, with the opening-and-closing of the fingers and thumb being driven by a gearing mechanism that connects to a single motor. The proof-of-concept device your team will be designing is the forefinger-thumb portion of the full-right-hand prosthesis.

For your custom design, there are important dimensional and operational requirements to consider and constraints to be met (these are outlined below). You will need to produce a solid model assembly of your design. Functionality of your design must also be demonstrated through dynamic simulation and rapid prototyping. Your team must also submit a technical report with simulation results and a complete set of engineering drawings that are in accordance with ANSI Standards. Your completed project (including technical report, prototype and all project files) is to be submitted following an individual and team oral assessment that will be scheduled in lab near the end of term.

2.2 Your Product

The proof-of-concept device your team will be designing is the forefinger-thumb portion of the full-right-hand prosthesis. The forefinger (i.e., index finger) and thumb are **driven by a motor** that has specific drive characteristics and is located near the wrist portion of the prosthetic. The **motor connects to the forefinger and thumb through a gearing mechanism**. The gearing mechanism is to be designed in such a way that the forefinger and thumb rotate: 1) in opposite directions with respect to one another (so as to simulate an opening/closing motion) and, 2) at a *specified* rotational speed that is slower than that of the motor. The **forefinger and thumb are to each rotate about a fixed axis at a specified location**. Finally, the **tips of the forefinger and thumb must contact each other within a specified volume of space**.

The **requirements** of this project are to:

1) Design a gearing mechanism that will incorporate the given input motor characteristics of the motor to produce the given rotational speeds of the forefinger and thumb.
2) Design the forefinger and thumb such that they contact each other within a given volume of space.
3) Design a custom mounting bracket that houses your gearing mechanism, supports the forefinger and thumb, and fits within the spatial constraints of the given right-hand prosthesis assembly.

2.3 Background Information: Anatomy of the Hand

A prosthesis is an artificial device that replaces a missing body part. The prosthesis in question is intended to replace a missing hand. While detailed knowledge of the hand, including anatomy and function, is not necessary for this course, knowledge of a few key anatomical terms and locations is necessary to better understand the intended function of the prosthesis and the design requirements your team must meet.

The hand is used for grasping and holding objects, exploring the environment (e.g., touching a surface), and communication and expression of motion. These activities are made possible by the high degree of mobility in the hand. This mobility is facilitated by the large number of joints (i.e., connection between two or more bones) present in the hand. Ideally, a prosthetic hand would replicate all the joints in the hand so as to provide the same degree of mobility and dexterity. However, accurate replication of the hand is not only extremely complicated, but also extremely expensive. As an alternative, hand prosthetics are typically designed to closely reproduce hand motion by replicating only the most prominent joints (e.g., fingers and thumb). An example hand prosthetic is shown in Figure 1 (the Raptor Hand by e-Nable).

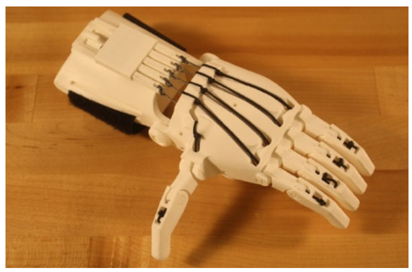

Figure 1: The Raptor Reloaded Hand Prosthetic (e-Nable)

Figure 2 show views of the side and the back of the hand. There are three landmarks that are especially relevant to your project. **Landmark 1** serves as the location of the motor's axis of rotation, and is located near the wrist. **Landmark 2** is the approximate site of forefinger rotation, and is approximately aligned with the joint between the forefinger and hand. **Landmark 3** is the approximate site of thumb rotation, and is approximately aligned with the joint between the thumb and hand. These last two joints are known as metacarpophalangeal joints (since they are the joints between the metacarpal bones, or hand bones, and proximal phalanges, or finger/thumb bones closest to the body). These joints are especially pronounced when the hand is clenched and a fist is made, and are commonly referred to as "knuckles".

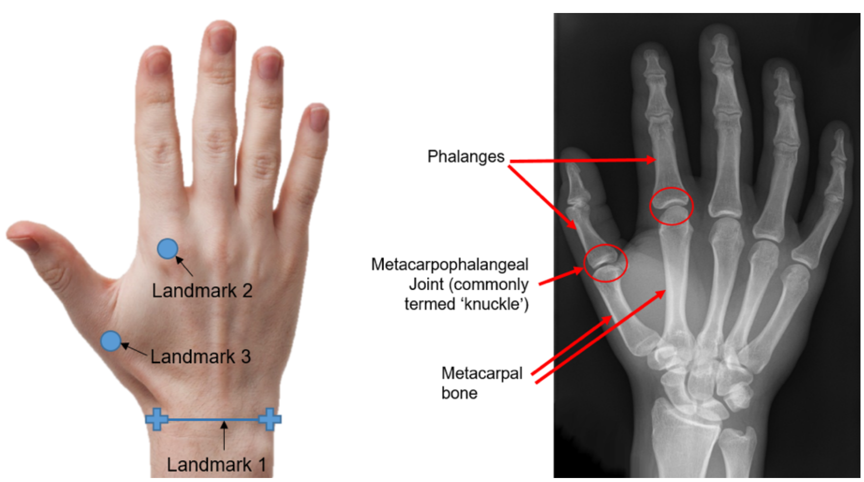

Figure 2: The Human Hand. (Left) the three landmarks relevant to your design project are identified. (Right) an x-ray of the hand with the key anatomy identified

The fingers in your hand each have 3 joints (including the knuckle) while your thumb has 2 joints (including the knuckle). These joints provide a great degree of mobility in your hand, allowing one or more fingertips to contact the thumb-tip in a wide range of positions. As a point of reference, touch the tip of your index finger to the tip of your thumb. Keeping them in contact, move them around while keeping the rest of your hand still. The locations in space that you're are able to move your index finger and thumb with their tips pressed together is known as the functional workspace.

For your project, it will be assumed that: 1) the forefinger and thumb are each rigid and only have 1 joint (the knuckle), and 2) motion of the forefinger and thumb is limited to 2D. Taking these simplifications into account, the path of motion of the forefinger-tip and thumb-tip can be visualized as a circular arc with center-of-rotation located at the knuckle (Figure 3). The location where these paths intersect is the point-of-contact between the forefinger-tip and thumb-tip (equivalent to the functional workspace). To provide flexibility in your design, it will be required that this point of contact lie within a given 2D 'window', similar to the one given in Figure 4.

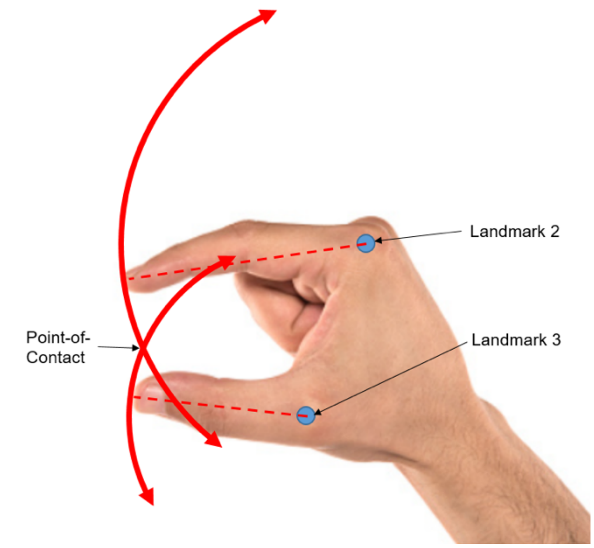

Figure 3: An approximation of the range of motion for both the forefinger-tip and thumb-tip. The intersection represents the point-of-contact

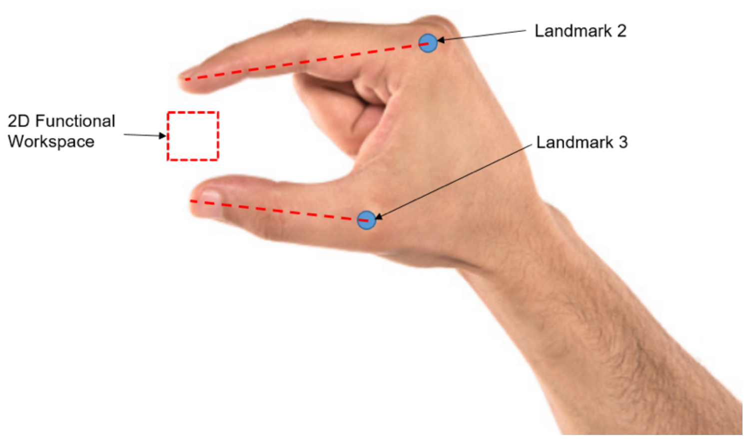

Figure 4: A graphical representation of the functional workspace. It will be required that the forefinger-tip and thumb-tip of your design contact each other someplace within this workspace. Note: this is a graphical representation only; detailed specifications are provided in Section 6.

3. Details of Project Requirements

3.1 Gearing Mechanism Design (Requirement #1)

Movement of the forefinger and thumb is controlled by a motor, which has been positioned near the wrist. Based on your group number, **each team will be assigned a unique motor rotational speed (RPM)**:

Group Number	Multiplier
1-4	**42.33**
5-10	**10.25**
11-35	**3.55**
36-100	**1.33**
101-200	**0.84**

For all groups, **the forefinger and thumb are to rotate at a rate of 0.125 RPS**. To replicate an opening/closing motion, it is required that they rotate in opposite directions.

Your gearing mechanism must connect to the motor at the input (rotating at a speed that is a function of your Group number – see above), and to both the forefinger joint (Landmark 2, Figure 3) and the thumb joint (Landmark 3, Figure 3) at the output. The forefinger joint is aligned with the forefinger axis of rotation while the thumb joint is aligned with the thumb axis of rotation (Figure 5). The motor must be placed inside the prosthetic frame as follows:

- The back of the motor must be flush with the side wall of the prosthetic frame, opposite where the forefinger and thumb are located
- **The motor's base can be positioned up to 6mm from the back wall of the prosthetic frame** in order to accommodate various designs and gearing ratios

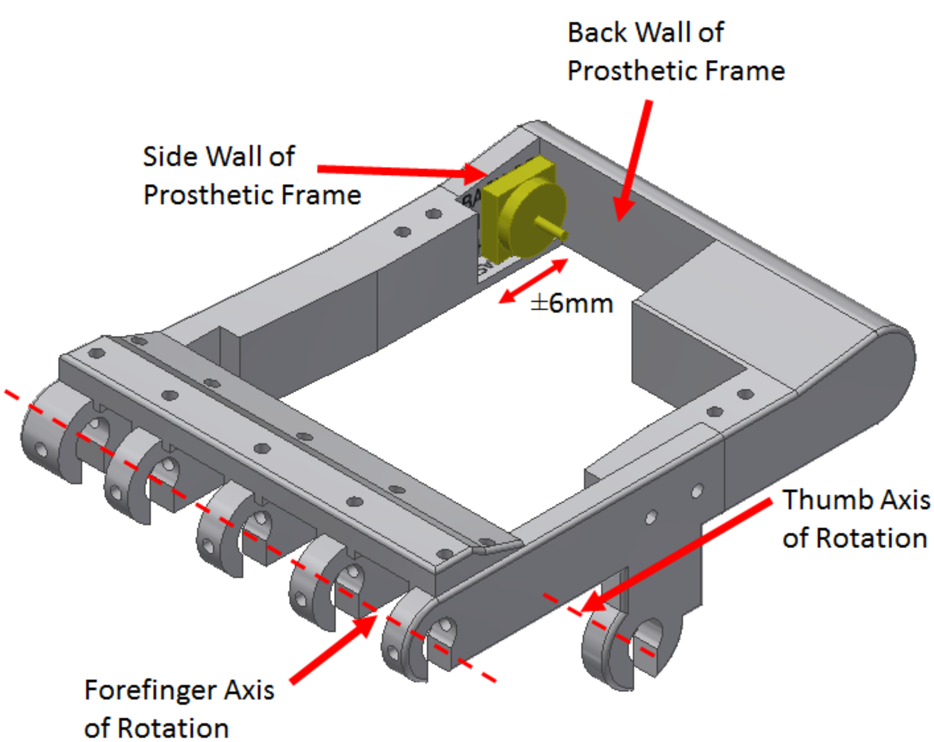

Figure 5: Partial assembly model of prosthetic frame with key landmarks indicated

3.2 Design of Forefinger and Thumb (Requirement #2)

Your design team is required to design the forefinger and thumb portion of the prosthetic. The forefinger and thumb are to be driven by the input motor and articulate about the respective axes of rotation (Figure 5). The forefinger-tip and thumb-tip must contact each other someplace within a 30-mm x 30-mm functional workspace. The location of this functional workspace is indicated in Figure 6 below. Beyond these requirements, the exact design of the forefinger and thumb (the length of each segment, the overall shape, etc.) is entirely up to you, and you are **strongly encouraged** to be creative! Just remember to meet the required objectives ☺

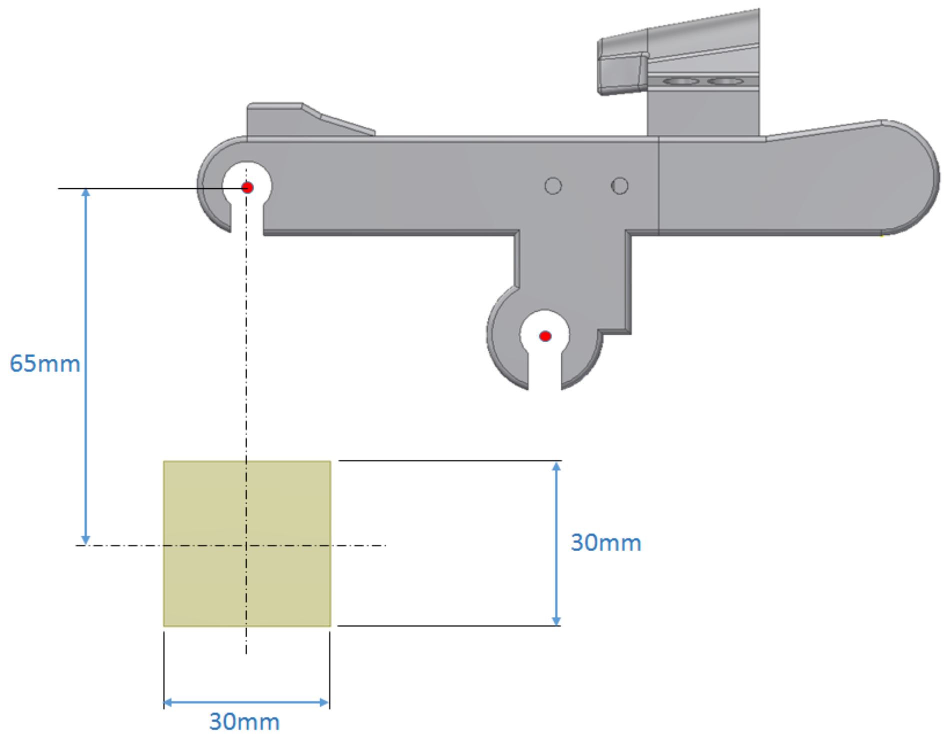

Figure 6: Location of the functional workspace 'window' relative to the forefinger axis of rotation.

3.3 Custom-Designed Mounting Bracket (Requirement #3)

Your gearing mechanism design must fit within the prosthetic frame (Figure 7) without modification to it, and **must include a custom-designed mounting bracket** for mounting all gearing components (e.g., shafts, collars, etc.) as well as the forefinger and thumb. When designing your mechanism to meet the dimensional constraints of the prosthetic frame, be sure to account for the dimensions of this mounting bracket.

Your mounting bracket is a **requirement** of the solid modeling and rapid prototyping portions of your project. Rapid prototyping will involve use of the 3D printers in the EPIC lab. However, you may use rods and screws (that are not printed) to secure components together. As with all printed components, **your team will be evaluated based on the appropriateness and utility of your design**. There are only 8 3D printers available at any given time to service upwards of 200 teams, and overloading the printers with long and overly-complicated prints may result in unexpected printer failure. Therefore, the use of the 3D printers requires that your team design your parts using as little printing material as possible. **Designing components that result in excessively long print times may result in you being denied access to the EPIC lab 3D printers until your components are re-designed**.

The prosthetic assembly (Figure 7) is not entirely enclosed, affording you some flexibility in your overall design. However, you should strongly consider the appropriateness of your design (including the final appearance of the prosthetic with the attached mounting bracket) when deciding where to place your components with respect to the prosthetic frame. For example, your design team should ask the following question: do any components extend outside the prosthetic frame to such a degree as to affect the overall function and utility of the device? If the answer to this question is yes, you strongly consider a re-design.

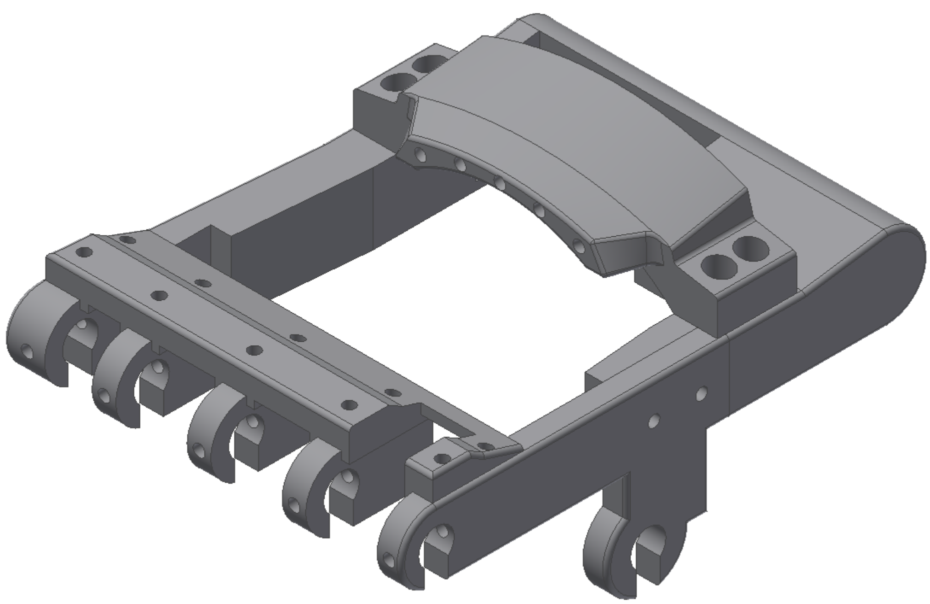

Figure 7: Isometric view of the prosthetic frame

4. Milestones Described

4.1 Milestone 0: Team Contract Agreement and Timeline

Milestone 0 Submission Checklist:

Functioning as a team requires some agreements on when a group will meet, how members will communicate, responsibilities, and a mechanism by which teams can communicate and resolve potential concerns before they impact the team/project. As such, the team must submit an agreement (including contact info) and a Gantt chart of project schedule (including agreed upon team meetings).

Your team will submit a report that includes:

1. Completed cover page
2. Team number
3. Each active member's name and student number
4. Signed team agreement from course textbook.
5. Proposed project schedule showing team meetings, member deliverables, and project milestones in the form of a Gantt chart (1 page).

4.2 Milestone 1: Preliminary Design Research Report

As a team, discuss and research the inner mechanical working of the existing product; however, focus should remain on the specific mechanism your team will be redesigning. Explain how the existing mechanism mechanically operates – your report must include scans of team hand sketches or screen captures of team Inventor models to illustrate your description – these MUST be created by your team.

Propose a design of how your team will redesign the existing mechanism based upon the space constraints and design parameters you have been given. This proposal must include concept drawings/sketches/models and calculations. Also identify any unknowns.

You may submit more than one design if the team members have different opinions. For the preliminary design the drawings/models/sketches do not need to get the exact geometry of the gearing components - appropriate basic shapes are acceptable (e.g. cylinders, disks, etc.). Submit the report with a cover page, a typed overview of how the mechanism mechanically operates (referring to your sketches using leader lines or numbers). Include a list of all planned meetings, the goals for those meetings, and the contact information for each member. Please number all pages.

Milestone 1 Submission Checklist:

Your team will submit a report that includes:

1. Completed cover page
2. Team number
3. Each active member's name and student number
4. Complete preliminary design report as outlined above (2 pages maximum, not counting diagrams and/or equations)

4.3 Milestone 2: 3D Printed Gears

This milestone is to provide an update of your progress. You are required to upload a brief (1-2 pages MAX) report to Avenue. Upon submission, PLEASE VERIFY THE UPLOAD WORKED. Late submissions cannot be accepted and will be assigned a 0.

Milestone 2 Submission Checklist:

Your team will submit a report that includes:

1. Completed cover page
2. Team number
3. Each active member's name and student number
4. A screen capture of the team's current solid model design
5. A photograph of the team's physical printed gears to-date (your completed cover page must be in the photo)

4.4 Milestone 3: Modelling, Engineering Drawings, and Documentation

Every member is expected to participate in each aspect of the project. Recall the design process from lecture, lab and tutorial. Referring to the design process the team may approach the project by:

1. Use hand calculations to determine an appropriate gear configuration to meet Design Requirement #1
2. Calculate an appropriate length and placement of the forefinger/thumb to meet Design Requirement #2
3. Hand sketch your solution according to your hand calculations to verify feasibility
4. Model each unique part in Inventor; Design Accelerator allows you to design gear pairs (We are using the **ANSI drawing conventions** with **metric values)**
5. Explain your design approach for your gear train
6. Assemble the mechanism in Inventor
7. Validate your design using Inventor's Dynamic Simulation Environment
8. Measure and graph data from your simulation
9. Design and model a custom mounting bracket to meet Design Requirement #3
10. Create a complete set of engineering drawings
11. Fabricate your gear train, mounting bracket and forefinger/thumb
12. Write a technical report

Please note that **Steps 1-8 above are not necessarily linear**! It is very common in Engineering Design to repeat the above steps (multiple times, even). Some elements may also be completed in parallel, for example, the technical report format and some content does not need to be completed at the end of the project. This is why the earlier you start on the project, the better positioned you will be at time of submission.

Technical Report:

Combine your design and modelling work into the final technical report. Accurate and efficient modelling, overall design, and presentation are significant considerations. The format of your report should be neat, structured, and organized. References must be in the IEEE format. You can find information regarding style guides in the Thode library, or online. The style guide by Turabian is recommended and also be used for 1P03. At a minimum your typed report should contain:

1. A cover page with your understanding and acceptance of the academic integrity policy
2. A table of contents
3. An introduction
4. A description of how the mechanism works
5. A set of calculations for the gear train design
6. Images of the probe graphs for Inventor's dynamic simulation environment
7. A summary table of what each team member contributed to the project
8. A summary of all team meetings and member attendance
9. A typed index of drawings
10. A complete set of engineering drawings that include detail and assembly drawings for your mechanism. Detail drawings must be properly dimensioned and the assembly should illustrate how the product is arranged. Each drawing must have a title, an author, and be numbered

<u>Project Interview</u>:

Your team / individual assessment will be during your assigned time in your week 12 laboratory. You will be asked questions related to your team design. There will be individual questions and group questions. Each member must be able to answer questions about any aspect of the design (calculations, part models, assembly models, system models, etc.).

By the conclusion of your team / individual assessment you will have to submit via Avenue the final version of your complete report (soft copy - see below for specifics) as a team. All Inventor software files and a softcopy of your technical report must be uploaded by the conclusion of your assigned time. Note that the work submitted will be evaluated after the assessment and it is imperative that your team ensure the work is complete and can be directly opened, compiled, and tested after being downloaded from Avenue. All members must be present for the assessment. Teams/members missing the assessment will be assigned a 0 for this Milestone.

Bring the following hardcopy items to the assessment:

1. Cover page with team number and signed by all team members accepting the academic integrity policy
2. A table of specific items that each team member contributed to the project
3. An exploded assembly drawing of the gear train design
4. Print out of probe plots from Inventor's Dynamic Simulation Environment

<u>Week 12 Final Submission Checklist</u>:

For your week 12 assessment, you must bring:

9. **HARDCOPY (printed)**: A cover page with team number and signed by all team members accepting the academic integrity policy, a summary table of what each team member contributed to the project, an exploded assembly drawing of the gear train, and a print out of probe plots from Inventor's Dynamic Simulation Environment.

9. **INVENTOR SOFTWARE FILES**: All Inventor files required to review/reproduce your parts, assemblies and draft files, as well as all files necessary to verify your dynamic simulation. Please use appropriate file names. Please ensure your software files can be opened on any computer running Inventor – the easiest way to test this is to email the files to another team member and see if they can open them on a different computer.
9. **TECHNICAL REPORT SOFTWARE FILES**: A soft copy PDF formatted technical report including cover page. Note that this is not a resubmission of part 1
9. **3D PRINTED FUNCTIONAL MODEL**: The 3D fabricated, assembled, and working model of your team design built to scale.
9. **BONUS MATERIAL**: Include a separate section to clearly show the bonus material. Clearly label all bonus software files.

4.5 Milestone 4: Peer Evaluation

In addition to your TA/IAI's evaluation, each team member must complete an Avenue report evaluating themselves and the other members on their overall work; this will factor into each individual member's final mark. This portion of the evaluation is implemented as a deduction. Members who clearly do not participate equally will be deducted. Any member not submitting a complete set of peer/self-reviews will have full deductions applied.

The peer review is process by a software application. You must strictly adhere to the evaluation format or your peer review submission will be automatically discarded. Submission format will be posted on Avenue. The peer review submission deadline will not be extended - no exceptions - please do not ask to submit your review after this deadline.

5. Team Dynamics

Working as a team can present challenges beyond the technical details. Teams are strongly advised to consider the Gantt chart very seriously and (at minimum) to schedule a weekly team meeting (at a minimum once per week). Agree on a form of communication and ensure to document each member's contact information. You will be submitting a summary of meetings and attendance in the technical report (Milestone 3).

Any team problems must be addressed to Dr. Doyle no later than November 8, 2018 by 5:00pm.

6. Overall Evaluation

Your work will be evaluated based on a completed and clearly documented design and simulation, structured and professional presentation, clearly written technical report, and the success and functionality of your prototype. The overall grade is 100% and a full marking scheme will be posted to Avenue.

Working as a team is a good way to learn from one another, but it presents its own challenges. It is not the point of this assignment that a single person does all the work and the others observe; each and every member is expected to participate equally in all areas of this project and each member will be examined on the overall project. Although you are working as a team, academic integrity is still an issue. Drawings and/or reports copied in full, or in part, may result in all team members being charged with an academic integrity violation.

Any student unable to explain the work for which they are assuming credit may be assigned a 0 for the entire project.

7. Bonus

The bonus is evaluated on a one-by-one basis. A maximum 10% bonus grade may be added to a project that demonstrates a unique aspect in regard to functionality or construction that is clearly beyond the scope of the project. A bonus may only be considered ***after*** all the ***required*** objectives have clearly been met.

8. Academic Integrity Statement

As a future member of the engineering profession, 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 and the Code of Conduct of the Professional Engineers of Ontario.

Submitted by [Full name, student number]

9. Clarification and Answers to Common Questions

1. **What is the module I should use?**
   As discussed in class and noted in lecture notes, a module value will not be provided. Using a module that creates very tiny teeth may help your calculations, but it very likely is unprintable. The advice provided in lecture and in lecture notes is that printing any feature smaller than 1mm is risky, but that teams should try the limits of the printer and their design by trying a test print.

2. **Do I need to print the hand prosthetic frame files? Can I modify the provided files to mount my gears?**
   You are not expected to print the hand prosthetic frame. This frame is also called a chassis. The term frame or chassis is a general term representing supports for the operation of the gear train. Your gear train frame/chassis must fit inside* the existing hand prosthetic frame. The maximum outer dimensions of your frame/chassis are limited** to the inner dimension of the hand prosthetic frame. Teams are encouraged to design a frame/chassis that is smaller than the maximum limits, but reminded it must also remain functional. *See item 3. **See item 4.

3. **The discussion has been that our designed frame/chassis must fit inside the existing hand prosthetic frame – does this include the threaded rods, the nuts, and/or the motor handle?**
   Only the frame/chassis must fit inside the existing hand prosthetic frame. Your evaluator will not deduct marks for the threaded rods, the nuts, and/or the motor handle interfering with the hand prosthetic frame.

4. **The discussion has been that the maximum outer dimensions of your frame/chassis are limited** to the inner dimension of the hand prosthetic frame – does this mean we are unlimited vertically above and below the hand prosthetic frame?**

As discussed the maximum height above the hand prosthetic frame should not exceed the bridge across the top of the hand prosthetic frame (given the curvature of the bridge, if needed you may approximate the full height of the bridge as squared/flat equal to the existing maximum height.)

The guidance for the maximum height/depth below the hand prosthetic frame has been to allow reasonable functionality as a hand prosthetic. In some cases this has been interpreted as an unlimited value. While we will accept some variation, a design which (excluding the connection the thumb axle) exceeds the approximate full height of the bridge as squared/flat depth should expect scrutiny if the design is reasonable.

The connection to the thumb axle should again be reviewed for its size. For example, if a final spur was axially connected to the thumb then its size would be reviewed to see if it was appropriate or if a better approach could have been taken to help minimize size.

5. **Do we need to worry about our gear train interfering with the hand prosthetic frame "knuckles"?**
   Yes. Part of the challenge of this project is working within the provided spatial constraints.

6. **Can our team use my personal 3D printer?**
   Yes, but only your team. This assumes you own a personal 3D printer and that you are personally + fully conducting the printing *for only your group*. This cannot be a commercial 3D printer. Printing for other groups will be considered an academic integrity violation.

7. **Can I use a friend's 3D printer? Can I use a 3D printing service? Can I use my family member's private company 3D printing facilities? Can I use a community / private club 3D printing facilities?**
   No. Printing outside of EPIC will be considered an academic integrity violation.

8. **Do I need to cut the threaded rods?**
   There is no need to cut the threaded rods. In fact, for safety reasons we prefer that you do not cut them.

9. **Will our gear train be connected to a motor for testing? How will our gear train be connected to a motor for testing?**
   As discussed in lecture, your gear train will not be connected to a motor. We will be evaluating your success in meeting the output speed based upon finger displacement, functionality, and the dynamic simulation. However, you must provide the evaluator a method of rotating your input axle in the same way a motor rotate the axle – this is easiest if you print and attach a simple handle, however, just extending the input axle (threaded rod) would suffice.

10. **Do I need to print the fingers?**
    Yes. These will be used to evaluate your team success in meeting the output speed and if your finger/thumb close correctly.

11. **How do we design our gear train to open and close the finger/thumb?**
    Once the finger/thumb are closed, you may assume the motor would reverse direction to open.

10. Change Log

Changes to this specification will be chronologically noted below:

- October 15 – multipliers added to section 3.1
- October 15 – output speed updated "**the forefinger and thumb are to rotate at a rate of 0.125 RPS"** in section 3.1

- November 7 – EPIC Lab access updated and milestone 2 deadline updated in section 1.3.
- November 7 – Clarification and answers to common questions, new section 9 added (Change Log section number modified to 10)