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April 5th, 2019

Dear Dr. Urwatta,

The issue of injuries within sports has existed since the inception of sports, however, little has been done about them. Sports injuries can come from several different circumstances; self-induced injuries, however, have the most potential for possible prevention. ACL related injuries are especially known for their career-ending impact on countless athletes. Our team is dedicated to developing a brace to detect high-risk movements and prevent further injury to the player by allowing immediate treatment.

The purpose of our design is to keep players from worsening their injuries. To do this, we hope to detect the potential for an injury moments before or as it occurs. The ACL has the potential to stretch and tear partially or fully. Detection of excessive force on the ACL allows coaches to be aware of the stresses placed on players bodies to prevent irreversible damage. The design is non-invasive and lightweight while maintaining functionality of current knee braces athletes wear. The system created is not meant to replace current technology available for knee ligament protection but add features to increase real-time data transparency between medical staff and athletes.

Developed with flexible and thin material, the brace utilizes sensors and two small microcontrollers to monitoring input. The device detects dangerous movements and accelerations in the knee within the medial and lateral direction. We know this device will save countless careers and are awaiting supplies to begin production.

Warm regards,

Bilal Ayyache Devin Catt Monica Malek

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Design 3 Final Report

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In signing this report and providing my PEO SMP (Student Membership Program) number, I certify that I have been an active member of the team and provided approximately equal contribution to the work. I take shared credit and responsibility for the content of this report. I understand that taking credit for work that is not my own is a form of academic misconduct and will be treated as such.

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1 Executive Summary

ACL tears are extremely painful injury with potentially lifelong eects to a person's ability to move. Athletes with torn ACLs are potentially never able to compete in their sport of choice. Not only is this a traumatic and upsetting experience for athletes, it is life-altering if the athlete competes at the professional level. Approximately 350,000 ACL reconstruction surgeries are performed in the United States and Canada annually. We hope to reduce the need for such invasive procedures by preventing ACL injury, either all together or preventing further damage after an injury occurs. There are two types of ACL injuries: partial tears and full tears. In fasted-paced adrenaline-filled moments, athletes cannot realize the damage undergone by body, worsening their condition. Using our device solves this classic problem and prevents athletes from permanent, life-changing damage to their ACLs.

After several proposed designs and prototypes, a two-part system consisting of a knee-brace and shoe addition with embedded electronics was selected. Part one consists of a familiar, classical cloth knee-brace with an embedded ex sensor and accelerometer, allowing for non-invasive, light-weight measurement and protection. The second part consists of a shoe addition containing a flex sensor and two pressure sensors. These two parts in unison allow the tracking of the angle of and forces on the knee. Using low-power integrated circuits to transmit data, the device allows for the real-time detection of potential injuries and alerts the coach and medical staff immediately to prevent further injury.

It was critical to have a non-invasive, comfortable device that allowed for full range of motion to not impede athletic performance. Using wireless communication allowed us to satisfy many requirements including knee protection, ability for foot and knee measurements, and communication with the sideline team – all without introducing new equipment for the player. Material for the brace was selected for a lightweight and comfort while being robust, hygienic, and allowing accurate readings from sensors. In addition, the sensors and controllers selected for the design were selected to maintain accuracy while being small so athletes cannot feel them during game. A flexible circuit board and cushioning around the circuits was also developed to minimize potential damage from external forces.

Risks are inevitable in any design due to countless unknown variables. One possible issue is uncertainty and approximations used in the design. Attempting to create a one size fits all device that requires precise measurements is challenging and may require customization for some users. The limited market is another risk. This niche market has little to no competition, however, lack of exposure and early adoption could lead to our solution not reaching its desired audience even though minimizes a long-term problem. In addition to this, potential competitors could notice this untapped market and create their own approach to the issue. This would be problematic for our business, as there are a finite number of potential clients. To mitigate these potential issues, several strategies are currently being implemented.

Future revisions will expand the scope and develop a preventative force to counteract ACL strain. One potential method for this is using thermoplastics to protect the knee from dangerous positions. Applying current to the fibres cause a contraction that can be used to counteract the strain on the ALC. Another improvement will be containing all sensors in one brace rather than having two separate systems. This would create substantial savings as less labor and material will be used, however, challenging to accomplish as changes in how a dangerous manoeuvre is determined are required.

2 Acknowledgements

We, as a design group, would like to extend our thanks and gratitude to a number of individuals for aiding us in the completion of this design project.

First, we would like to thank Dr. Brandon. His assistance in defining our problem, as well as expertise and knowledge of knee bio-mechanics, made this project possible.

We would also like to thank Abdulrahman Al-Abassi for his experience in design and for his everlasting patience for our questions. Encouraging us to limit our scope not only allowed us to make a design that can save athlete's careers, it prevented us from under-delivering due to over-ambition.

One other individual we would like to thank is Dr. Ukwatta. His extensive knowledge and guidance throughout the semester was critical throughout the entire design process. We may only have you as a mentor for one semester, but your guidance will stay with us for our careers.

Lastly, we would like to thank everyone who contributed to this project in some way. So many people have played a role in the success of the project that we are unable to personally name everyone. Whether providing feedback, insight, support, or (and especially) food, your contributions have not gone unnoticed. From the bottom of our hearts, thank you.

Contents

List of Tables

List of Figures

3 Introduction

The aim of this report is to give a complete context and walk through of the design process, and give information about the technical and non-technical aspects of the knee brace made to detect potentially dangerous ACL movements for athletes.

ACL tears are an extremely prevalent and life affecting injury in sports. Once an athlete has torn their ACL, they will not be able to play sports the same way again, as ligaments do not heal. Once an ACL has been torn, athletes often attend very expensive physiotherapy, to mitigate the pain of their injury. Athletes playing high risk sports such as Football, Volleyball, and Basketball are at an especially high risk of tearing their ACLs, and those sports are of special consideration in this report.

The current solutions for athletes tearing their ACLs is for athletes to wear knee braces a preventative measure. This solution does nothing to gain information on how an athlete is moving.

The scope of this endeavour is to design a device that will track the athlete's movements, and will send information to a coach if a force threshold deemed dangerous has been exceeded by the athlete. This will allow coaches to track the health of their players.

After determining the scope of the project, a substantial amount of background research was conducted to fully understand the constraints and criteria needed for project success. Afterwards, potential solutions were brainstormed and evaluated, and the best solution was determined using a decision matrix.

The best solution was determined to be a flexible cloth sensor with a flex sensor in the knee and a secondary pressure sensor unit to be embedded in an athlete's shoe. The circuit subsystems were designed, and the actual cloth brace was modelled to determine the technical success of the systems. Afterwards, a break-even analysis was performed to ensure the economic success of the product. An LCA analysis was performed to determine the environmental impact of the design, as well as the societal impact and the risks involved with the design.

4 Problem Description

4.1 Problem Overview

Research estimates that nearly 350,000 ACL reconstruction surgeries are performed in Canada and the United States annually. The Anterior cruciate ligament is considered to be among the most economically costly sport injury, frequently requiring expensive surgery and rehabilitation. 76% of these injuries occur during dynamic movements when playing sports that primarily involve pivoting such as basketball, football, soccer, and in sports such as volleyball when landing after a jump [44].

Figure 1: Landing with knee extended and adduction moment causing stress to the ACL [44]

A faulty mechanic during a dynamic movement is identified as the main cause of an anterior cruciate ligament injury [43]. Such movement causes an excessive force to be exerted on the joint in the knee. Faulty mechanics can be prevented by using a knee brace. An unequal limb loading, a lateral displacement of the trunk, or switching in movement direction frequently can be great examples of faulty mechanics. An individual in a fatigued state is more prone to damaging their ACL as they perform more frequent faulty movement patterns [43]. Addressing and preventing these faulty movement patterns can help minimize the risks of injury. This project will be able to address these faulty movement patterns, and notify the coach of the danger before a tear occurs. Exercise modes such as strength training, neuromuscular training, and plyometric can also help in addressing these faulty movements' patterns [43]. A list of exercises will be supplied to the user through the user interface. Such exercises help strengthen connective tissues in the joint by improving resistance to stress and strain during rotation, flexion, and adduction. The table below describes the relationship between the maximum strain and angle applied on the connective tissue. Such data can be used to design a medical device that can alert or notify user when connective tissues is susceptible to failure.

Maximum strain of connective tissue bundles

Connective tissue	Bundle	Maximum strain		
		Flexion (@angle)	Rotation (@angle)	Adduction (@angle)
ACL	aACL	0.128 (120°)	0.041 (30°)	0.051 (15°)
	pACL	− 0.004 (0°)	0.010 (30°)	0.144 (15°)
PCL	aPCL	0.120 (100°)	− 0.044 (30°)	− 0.040 (− 15°)
	pPCL	0.030 (0°)	0.216 (30°)	0.228 (− 15°)
LCL	LCL	0.036 (0°)	0.139 (− 40°)	0.202 (15°)
PL	PL	0.073 (110°)	0.188 (− 40°)	0.208 (15°)
MCL	aMCL	0.046 (0°)	0.138 (− 40°)	0.184 (− 15°)
	iMCL	0.061 (0°)	0.148 (− 40°)	0.195 (− 15°)
	pMCL	0.037 (0°)	0.099 (− 40°)	0.141 (− 15°)
	aDMCL	0.037 (0°)	0.357 (− 40°)	0.309 (− 15°)
	pDMCL	0.001 (0°)	0.275 (− 40°)	0.240 (− 15°)

Figure 2: Maximum strain of connective tissue bundles [43]

A dysfunctional ACL leads to knee instability as the ACL is considered to be one of the four major knee ligaments [44]. Knee instability makes participation in sports difficult and sometimes impossible depending on the damage caused. Such injury forces semi-professional and professional athletes to undergo an ACL reconstruction surgery to help them get back on the field [44]. A standard ACL rehabilitation treatment takes many athletes 7 to 9 months to complete, not only does this mean the end of their athletic season, but also will interfere with them keeping up with the competition in the sport they play [44]. The figure below describes the increasing amount of NFL linemen that went through ACL reconstruction surgery and did not return to play afterwards over time [44].

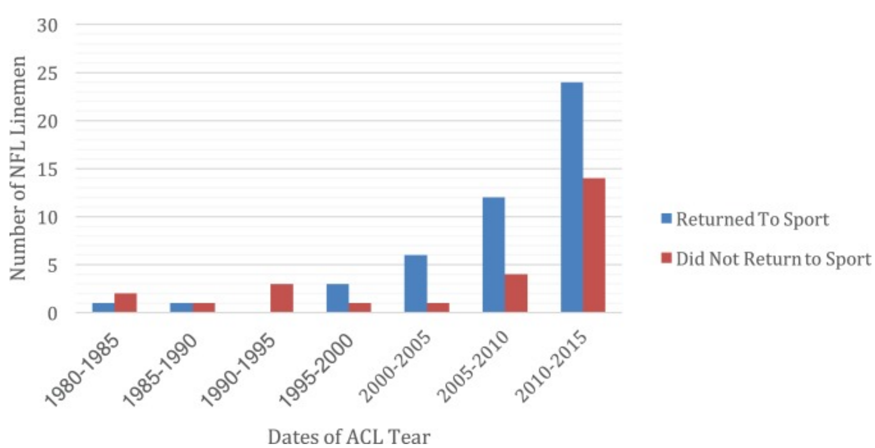

Figure 3: ACL tears in NFL Linemen since 1980. ACL, anterior cruciate ligament; NFL, National Football League. [44]

4.2 Current Technology

The current available technology for knee braces can be very similar. A typical knee brace is made of cloth, has some sort of strong framing woven with the frame, and can be put on like a sock [52]. Knee braces can very a lot in price range, and can be as cheap as approximately $20 and on the pricier end, can exceed $2000 [45] [54]. Current products available commonly utilize a sleeve-like structure around the knee to support the athlete during activity [45]. Some products use straps to achieve a tight fit to support an athlete [47]. Some of the more heavy-duty knee braces on the market utilize a solid frame and hinges to create structural supports for the knee during activity [48]. Some knee braces can resemble an exoskeleton to support the knee using extremely tough metals and frames [46].

One unique product available is Kinesiology Tape (brand name KT Tape). KT tape works by applying a piece of elasticized tape at varying levels of tension on the desired limb [51]. According to KT Health, LLC, KT tape supports joints by reducing pressure on the joints, alleviating pain, and aids muscle contracting which should help prevent over extension [51]. It was found that there is no significant reduction in muscle activity, as found by an EMG, however there was a statistically significant reduction in postural sway when Kinesiotape (general name for KT Tape) was applied (Figure 4).

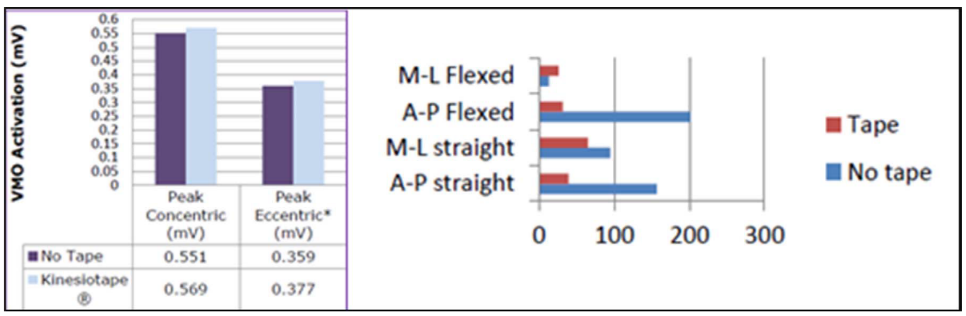

Figure 4: EMG (mV) readings (left) and Postural Sway (mm) Values Before and after Kinesiotape Application (right) [50]

4.3 Technical Problem

The trauma of tearing the anterior cruciate ligament (ACL) to an athlete is a major disruption within an athlete's life as not only is their athletic performance affected, but every aspect of daily life has now changed. Specifically, within high caliber sports where athletes turn their performance into a career, an ACL tear can cause an athlete's life to change drastically through irreversible damage. A current protective solution for high performance athletes is to wear stabilizing braces during all events. These braces not only restrict movement but the added weight can negatively impact the athlete's performance. Creating a device that implements sensors to track knee movement allows training staff and coaches to have more information about an athlete during performance, allowing coaches to remove players from dangerous play. Training staff will then be able to quickly and accurately determine the correct course of action to return the athlete to the field of play as soon as possible.

Many individual components of the overall design must be considered starting with where the ACL lies. The ACL originates at the tibial plateau of the femur and inserts onto the lateral femoral condyle of the tibia preventing anterior movements of the tibia. As such, direct muscle engagement of the quadriceps and hamstrings as well as the positioning of the femur relative to the tibia has a massive impact on the amount of stress the ACL is put under. Due to this, the device's design must account for muscle engagement of the upper leg, the valgus movement of the knee, the positioning of the tiba relative to the femur as well as the bending angle of the knee. While the device will have many components to measure all of these criteria, the overall system will have to factor and weigh them appropriately in order to build an accurate model for the forces the ACL experiences.

Working alongside coaches and athletes to provide a product meeting all constraints and criteria is a necessary step. This integrated approach improves upon current preventative athletic devices used within similar applications. By identifying and assessing ACL injuries in high caliber athletes, coaches will have access to more player data allowing them to understand the force and trauma the player just experienced. As such the athletes can focus on the game without the concern of a high medical issue as the coaches are receiving active electronic monitoring of the stresses directly placed on the ACL

4.4 Economic Impact

The anterior cruciate ligament injury is definitely a very common knee injury especially among young and active individuals, however the economical impact plays a big part in understanding why a solution to such issue is required [43]. The MultiCenter Orthopaedic Outcomes Network released a report in 2013 which claims that a mean lifetime cost from a typical patient undergoing ACL treatment was $38,121 compared to $88,538 for rehabilitation. This shows that treatment to such injury is very expensive creating an economical impact in society. The graph in figure five demonstrates an increase in rehab cost from start to completion. Rehab starts at almost $40,000 and increases to $160,000. An average player in the MLS league makes an approximate of $148,693.26 per year. Assuming that an MLS player undergoes an ACL injury, a year worth earnings will be spent to get the player back on the field [43]. If player is financially restricted, recovery may take longer than 1 year which drastically affects his career in sports. When recovery cost is that high, such economical impact leads to other societal impact in the community.

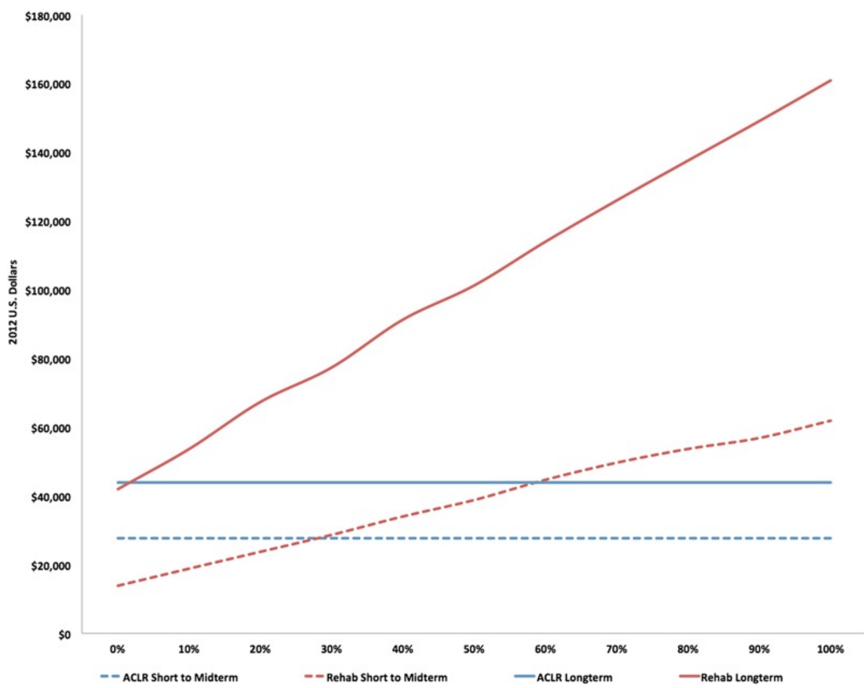

Figure 5: Sensitivity of total cost to the rate of instability after rehabilitation. [43]

4.5 Societal Impact

The high cost of treatment introduces a new problem as 20-30% of injured patients are left untreated due to financial challenges [43]. An untreated ACL injury would leave the patient unable to trust the stability of the knee and prevent them from resuming their career in sports. An untreated knee injury acts as a barrier that prevents the patient from performing daily tasks or activities which leads to depression in some cases [43]. The cost of a torn ACL treatment is substantial, and the results of an untreated ACL can lead to disorders, loss of motivation, and unemployment. Such results introduce societal problems in the community. The graph below shows the increase in cost of rehab as instability increase [43].

4.6 Environmental Impact

As with any manufacturing endeavour, the materials needed in typical ACL braces have an impact on the environment. To minimize a negative impact on the environment, the life cycle of the product needs to be considered. There is little environmental impact from the act of a person tearing their ACL, but the materials used to create ACL braces need to be considered when creating a brace. Most braces in today's market is made with cotton which is not environment friendly due to the pesticides used when producing. Cotton will be replaced with a nylon fabric due to the added stretch and durability within this product application. Nylon provides an added source of compression and protection an athlete requires. Nylon is a slightly recyclable material but has an alternative that can be further looked into. Econyl is derived from recycled plastics and shows similar properties while being more environmentally friendly[58].

4.7 Literature Review

There are several aspects to understand about the problem at hand before even attempting to design a solution to the problem. As with all sports injuries, it is important to consider important biomechanics, anatomy, and pathology of injury. The impact to the person who was injured, and the impact to the health care industry must also be considered.

It is important to understand the biomechanics behind the problem at hand. There are several ways to reduce loading on the knee, which fall under one of two methods: reducing the adduction moment around the knee or reduce muscle activity [37]. To reduce loading on the knee, one can change their stride, use a stride altering device, or surgically alter their limb [37]. Obviously for sports applications, altering stride is not ideal. Unloading the knee can help reduce fatigue and wear on it [37]. However, unloading the knee can also lead to issues, if unloaded a large amount. To reduce muscular activity of the knee, a player can adopt altered stride kinematics, or use a restrictive brace, both solutions are less than ideal [37]. The main forces that act of the knee in a day to day situation are due to the adduction movement of walking, and laterally stabilizing the knee [37]. Having a firm grasp on the biomechanics of the ACL can help give insight on what could go wrong in an injury and lead to ways to prevent injury.

Furthermore, it is necessary to understand the anatomy and its limitations. The ACL can extend to approximately 40mm, when the knee joint is fully extended [38]. The ACL provides a majority of the resistance for movements of the tibia and the femur [39]. The Quadriceps and Hamstring muscles results in translational forces directed in the anterior and posterior directions [39]. The forces exerted on the ligament vary from angles of 0 and 60 degrees [39]. During typical squatting and lunging exercises, it was found that the peak strain in the ACL was around 2.8% to 4% (around 100N to 150N) at angles between 0 and 30 degrees [39]. The Ultimate Tensile Strength of the ACL found in a normal human adult was around 2000N [39].

To understand why ACL injuries are an important problem to be considered, it is important to consider that injuries are not just a mechanical problem, and that actual people are affected with every injury. It is more common for an ACL injury to happen during high-impact activities like sports than low-impact activities such as squatting or walking [40]. An ACL injury was 7 times more likely to occur in competitive game/environment than during practice, as athletes try to push their bodies to the limits where their ligament cannot handle the high stress applied [42]. Women's soccer had the highest injury rate, followed by men's football, whereas a sport like ice hockey is relatively low on the list [36] [42]. In sex-comparable sports, women in sport had a higher rate of tearing their ACL compared to men [42]. In addition, women are 6 times more likely to tear their ACL than men, as their femoral notch is smaller, causing a smaller area for pressure to be applied [36]. Children are more likely to participate in high risk activities for ACL tears, so they have a higher risk for injuring themselves [36].

When designing some kind of device to restrict ACL tearing, the athletic motions that happen when injury occurs is important to study. Interestingly enough, two-thirds of ACL injuries are due to non-contact injuries [36]. The most frequent motions where an ACL is torn are when an athlete lands from a jump "lock-kneed" on one foot or when they decelerate and accelerate extremely quickly in a motion akin to pivoting [36].

Knee injury anatomy is significant to understand if a method of prevention is to be found. Anatomically, an ACL tear can happen when the tibia is translated forward relative to the femur [36]. Combined with rotation of the tibia, a lot of tensile and shearing forces can be placed on the ACL, causing damage [36]. The multiple planes of motion can be a large contributing cause to the large forces exerted on the ligament during injury [41]. It is more common to injure the ACL when the knee is hyper extended, in fact when the knee is near full extension, the highest amount of forces are felt [41].

It has been found that wearing a knee brace can reduce external knee adduction movement, which can alleviate pain in people suffering with pain in their knees [49]. Wearing a knee brace can help restrict knee adduction movement [49], which can be a risk factor for tearing an ACL.

4.8 Scope and Objective of Project

To create a device that can detect when an athlete is performing a movement that is placing their ACL at risk, when such a movement is detected a coach or training staff will be notified as while as receiving quantifiable data to help in risk assessment. This device will not be used as a preventative brace, the device will only be used for detecting dangerous movements and forces on the ACL. Acting on the data collected from this device to restrict knee movement to hopefully prevent an ACL tear can be explored in a further design project or research.

This device is not intended to be used as a rehabilitation tool, by measuring the angle of movement this device is designed to detect or prevent movement outside of a safe range of motion in rehabilitation a slight pushing of boundaries is needed to continue to make progress as such out device will not be a suitable tool to use.

This device is also not a diagnostic device as such a medical professional should still be the final decision on an athletes ability to remain in the game. The intention is to provide more information to the medical professionals about the trauma but while remaining as minimally invasive as possible.

This device will not be able to mitigate risk involved with compression injuries to areas like the meniscus. To remain as minimally invasive as possible there is no way to support a separation between the femur and Tibia, as such a injury to the meniscus might cause irregular data and be detected but this device will not be speciously report such anomalies.

5 Project Constraints

Table 1: Table of Constraints

Constraints	**Explanation**
The design solution must not restrict knee motion from 185° to 10° of bending during athletic activity.	The specified range of motion covers the range of angles that a knee can bend at, without allowing hyperextension of the knee, which can be a risk factor for tearing an ACL.
The design solution must only restrict 3 degrees of freedom of knee movement. The degrees of freedom of interest are posterior-anterior translation, lateral-medial translation, and external-internal rotation.	The degrees of freedom of interest will restrict the translational movement of the Tibia relative to the Femur, which is one of the largest hazards which can lead to the tearing of the ACL.
The design solution must be able to detect anterior-posterior stress of the ACL equivalent to 52N/mm^2 at a rate of 100 readings per second (Figure 7).	The design must be able to detect a force deemed dangerous (gotten through mechanical analysis) and must be able to check if such a force is exerted at a sufficient rate.
The design solution must be able to wirelessly transmit data to a person outside of athletic activity that the athlete's knee has accelerated above the target threshold.	The design solution cannot feasibly have long wires connected to a terminal, as that would inhibit athletic activity, so for the design solution to be able to transmit data wirelessly to a person monitoring the health of the athletes is a necessity.
Any electrical components part of the design solution must either be removable or be water resistant enough such that a user will be able to wash the device in a household washing machine.	Hygiene is a necessity for wearable devices, the build up of bacteria on the surface of the device would be detrimental to the athlete. As a result, the device must be able to be washed. To protect the integrity of the electrical components, the device must be able to safeguard the components and circuitry, or be able to detach from the device.
The design solution must be compatible to be worn with knee pads for basketball, volleyball, and football, so that if necessary, an athlete can wear the design solution with to any protective equipment.	To be able to wear the device, the athlete must not be put in a hazardous situation, therefore, the device must be able to be worn with other protective equipment necessary for sports.
The design solution must be at maximum 200g.	A typical athletic knee brace weighs around 150g, without any electrical components or sensors. Even with the extra functionality of the sensors, the proposed solution should feel as similar as possible to the athlete as a typical knee brace available on the market.

6 Design Criteria

Table 2: Table of Criteria

Criterion	Explanation
The design should be as lightweight a possible.	To allow the athlete to play at their peak ability while wearing the device, the device should be as light as possible so the athlete will hardly notice they are wearing the brace.
The design solution should have the maximum possible useful life cycle.	To be environmentally friendly and viable, the useful life cycle of the device should be as long as possible.
The design solution should minimize end cost to the user.	To be commercially viable, the device should not be financially cumbersome on the athlete.
The design solution should be made out of biocompatible materials and does not cause any lesions of the skin of the athlete.	To ensure comfort, the device should not irritate the skin of the athlete wearing it.
Through manufacturing, transporting, and after the useful life cycle becoming waste, the design solution should minimize its detrimental effects on the environment.	As the impact on the environment should always be a consideration, the environmental impact should be minimized.

7 Design Solution

7.1 Design Process

Understanding the forces that act on the knee are crucial to the success on the design. Once the forces on the knee are understood, they can be detected an then the information ca be used.

The bones that are important to consider during an ACL tear are the Tibia and the Femur. These bones will be significant in modelling the human knee as a two member system, to understand what forces are acting on the knee at certain angles of bend. While the Fibula articulates with the Tibia, it does not directly come in contact with the ACL, and for the purposes of calculation, it can be disregarded for the purpose of modelling as a two member system.

Modelling the knee as a two member system, as well as using known properties and dimensions of muscles, ligaments, and bones, a force threshold will be able to be determined, as the purpose of this device is to detect when a force on the knee has surpassed said threshold. The threshold will be determined to be equivalent to the stress on the ACL to tear it, with a safety factor to comfortably have a range of forces, without impeding on play.

While mechanics and biomechanics are important fields to consider when building this device, a bulk of the technical effort will be put towards circuit board design, signal processing, and coding the microprocessor, and monitoring system for coaches.

The features of the microprocessor are important to be considered when creating this device to detect dangerous ACL forces. As a result, the interactions between the sensors, microprocessor, and the transmitting device to the athlete monitoring device will need to be designed and implemented.

Furthermore, the microprocessor and the athlete monitoring system will need to be coded. The microprocessor needs to be coded such that it can receive signals from the sensors that are used, perform some calculations to determine the forces on the ACL, and if the force has passed a set threshold, found using the mechanical analysis, the microprocessor will transmit a signal to the monitoring system a coach has.

Finally, the monitoring system will need to be designed and coded. It will most likely be an iOS or an Android app, so a coach can have a smart phone with the data of all their players readily available during play.

The main goal of the circuit is to collect information that is required by the algorithm created to detect danger. The application consists of two circuits that communicate together using an SPI interface. Both circuits are powered by a chargeable battery. Hardware was implemented to charge these batteries and notify the user when battery levels are low. The first circuit will be placed by the knee. This circuit consists of a gyroscope, a sensor that reads the X Y and Z directions, and a flex sensor that reads the angle of the knee. The main objective of the first circuit or in other words the master is to collect data from the second circuit or the slave, and store the data into the Arduino chip for analyzing. Algorithms will be implemented into the ATMega chip (arduino) and collected data from all 5 sensors will be used to notify the coach if a wrong movement was committed. The Master circuit will communicate results with the coach through wifi that is provided by the ESP chip. ESP chip provides wifi communication with the user interface which is an application that the user can download through app store or the play store making it available on all platform. Coaches can download the application on their IPad and monitor their athletes. The second circuit will be placed by the foot. This circuit consists of 2 pressure sensors and a flex sensor. The main objective of this circuit is to collect information using the pressure sensors and the flex sensor, and provide the master circuit with the information needed for the algorithm to detect any injuries.

7.1.1 Design Approach and Strategies

Prior to any solutions the problem definition was clearly identified along with the specific part of the problem that could be solved with a device. Within this solution the main focus was on the detection of movement in the medial and lateral axis of the tibia relative to the femur. Identifying this constraint allowed for each design to detect this important movement at a different approach. Information gathering from literature about the length of movement in the medial and lateral direction along with the understanding of regulations on medical devices allowed for the development of a viable solution and alternatives.

7.1.2 Idea Generation

Multiple approaches of idea generations were discussed to obtain unique solutions to the current problem. The first approach was to have every group member individually come up with a solution after the lab. This allowed every group member to have enough time to think of a creative solution without being influenced by other group members. After the individual solutions were generated a group meeting was scheduled to discuss all of the potential options and try to integrate the best parts of each design into one shown to be the most effective in solving the current problem at hand.

7.1.3 Alternative Design-KT Tape with Sensors

The general idea behind this design is to use disposable, elasticized, kinesiology tape where the sensors to detect knee movements are able to snap in place in the tape, once applied to the knee

7.1.4 Alternative Design-Tension Band

This design is based on the is to use a regular small knee brace that conforms tightly to athletes lower legs while it provides support on the lateral and medial side of the leg. Tension bands will be added to the design running poster and anterior to the knee(**??**).

7.1.5 Alternative Design-Full length Supportive Leggings

Full length leggings similar to athletic pants worn by athletes will incorporate sensors on the quadriceps, a tension knee brace for support along with 2 sensors on the knee brace detection motion and movement of the athletes femur and tibia.

7.1.6 Alternative Design-Metal Frame

This design is based off of current high performance knee braces, it would involve sensors placed throughout the aluminum frame of such bracing systems with the circuity and power being sealed in.

7.1.7 Alternative Design-Automated Cloth Brace

The general idea behind this design is to connect data from sensors and send to a micro controller where data is collected and shared with the coach wirelessly.

7.1.8 Proposed Preliminary Design Solution

Based off several of the alternative solutions, a preliminary design was created. The device is a variation off of the automated cloth brace alternative design, however, is split into two sub-systems.

Instead of having just a cloth knee brace, some of the electronics will be embedded into the shoe of the user. The cloth sleeve will still contain a micro-controller with an accelerometer and a flex sensor to find the acceleration in the x, y, and z directions, as well as flex angle. Embedded in the user's shoe will be another micro-controller connected with two pressure sensors and another flex sensor. These will be used to find the shank flex angle and pressure applied through the foot.

As well as integrating the data from all of our sensors to a companion application for coach's to see live feeds of their athletes ACL health. This will allow for coach's to better understand what kind of damage the athlete may have just experienced. This aspect is extremely important to protect the athlete from further damage instead of allowing the athlete to play through injury.

Design Merits The first subsystem is similar to a cloth sleeve knee brace. Embedded in the cloth sleeve will be an ESP8266 WiFi-enabled micro-controller connected to a multiplexer. The multiplexer is required as ESP8266 micro-controllers only have one pin for analog input. To solve this problem, multiplexers are used with each controller to rapidly change the sensor being read from. By sampling at a fast rate, all sensors can be read from in a reasonable amount of time.

The second system embedded in the shoe is connected to the first ESP8266 micro-controller in a slave-master configuration, where the controller built-in the shoe is the slave and the controller embedded in the sleeve is the master. This avoids the potential issue of connecting the sensors on the foot to the micro-controller on the sleeve with wires, as there would be potential strain on the wire connections.

To power these two sub-systems, rechargeable batteries will be connected to the devices. The cloth brace will be connected with a USB adapter so it can be easily recharged. The system in the shoes, however, will be charged using a magnetic induction charging system. This will allow for the system to be fully embedded into the shoe without having to worry about making it removable. The batteries will be designed to last at least 3 hours on a full charge, however, the system can be easily recharged when the athlete is on the sidelines during a break, or during storage after a game.

Design Limitations that must be Considered

- Limitations in the battery capacity based off of physical size restrictions
- Potential impact and pressure on electronic components of device
- Size limitations to reduce restrictions to athlete

- Noise reduction and elimination

These limitations will be considered when finalizing the design to accomplish the project goals while not impacting the athlete's performance or comfort.

Additional Details about Selected Solution The device will connect to a companion device for the coach to alert them in case of potential injury to the player. This will be a standalone device to receive data from the players in real time, process the data for any potential anomalies in the players movement, and prompt the coach to act if there is a detection. This will be done with a simple tablet device connected to the wifi-signal of the master ESP8266 modules.

7.2 Detailed Final Design

7.2.1 Solidworks Model

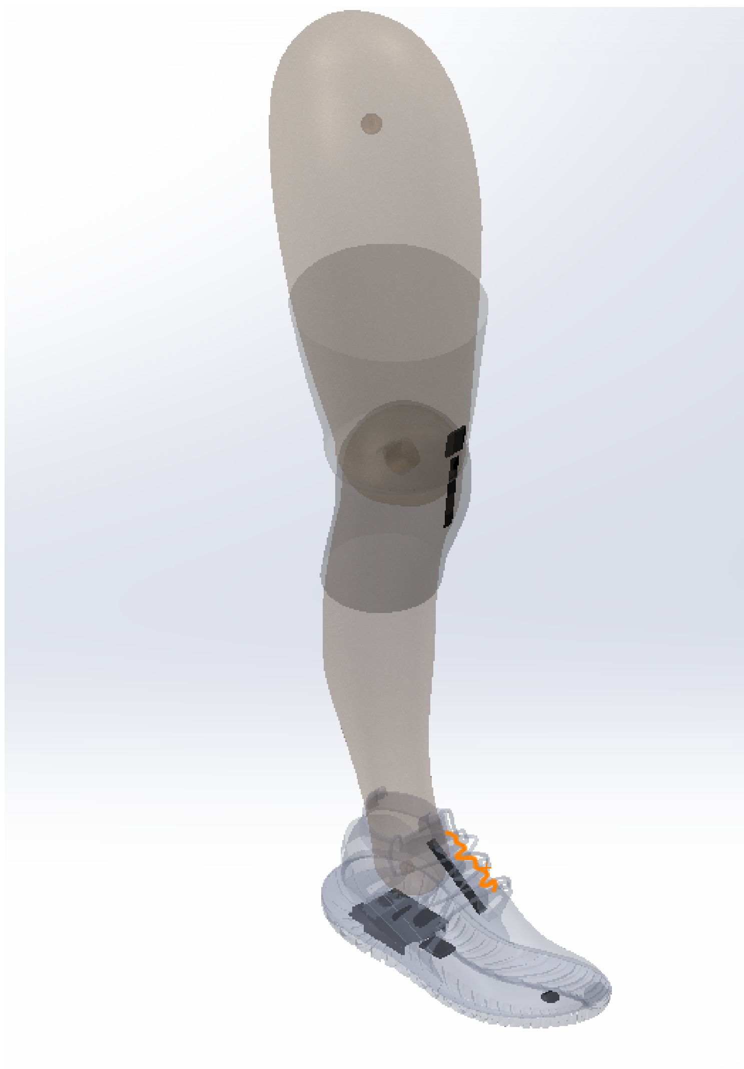

Figure 6: Soildworks Model of the Final Desgin

7.2.2 Design Merits

By keeping the design as light as possible and allowing for maximum comfort,ease of application as well as being applicable to multiple sports. These factors are the most important to us in our design and as such this design allows for accurate modeling without inhibiting athletic performance. As such by separating the knee sensors and foot sensors into sub-systems this allows the final design to keep all of these traits. Improving on our proposed preliminary design with modifications and additions to eliminate the limitations that were effecting that design iteration. The battery capacity itself was not able to be expanded without making compromises elsewhere in the design, as such the battery life was left at a capacity that should allow for the completion of any athletic event between charges. But with the addition of wireless charging coils in the shoe sole and above the knee on the compression sleeve will allow for players to charge these components without plugging them in rather placing them in a specialized compartment of their locker. By placing padding strategically in the compression sleeve the athletic performance of the athlete should not be effected while adding protection to the circuity of the design. Noise reduction of the system has been addressed by selecting appropriate materials for both the compressive sleeve component and the supporting material of the shoe sole. The companion application will be designed to give quick and easy data by colour coding the amount of force experienced with how close it came to the threshold set by a Finite Element Analysis and 2-Force Member Analysis with a health factor of safety. A more detailed breakdown of the forces will be stored and could be integrated into film breakdown to help with techniques which are put into practise to protect the athlete such as cut blocks in football.

7.2.3 Design Limitations

The main issues that arise from choosing this design include the impact resistance of the sensors as well as the cost of the design are both negative aspects of the design. The impact resistance of the design is being bolstered by the padding in the compression sleeve portion of the design. This amount of impact resistance will work for almost every athletic position, however in extreme positions like football defensive and offensive lines another layer onto of our design would be required to protect our sensors from the extreme amount of impact that can be produced in situations such as a cut block. However most lineman already wear metal knee braces to protect against injury. By keeping our padding and compressive sleeve thin we are able to maintain a level of comfort for lineman to wear our sleeve under their current brace system. The cost of this design does limit its marketability to lower end athletics but the target market we are currently producing involves high caliber athletes and as such it is in their best interest to protect their body as it is their best asset.

7.2.4 Next Steps

In 5 years time the revision will be needed as the first products are finishing their life cycles, expected updates are to improve the weight and communication system power consumption and by extent decreasing the battery size. At this point marketing the product to higher end as well as more expensive markets with professional money behind them, may become a viable option to increase the products market. If this becomes reality the improved number of products in use will help to refine the product even further.

In 10 years another revision will be implemented, this revision will be focused on improving the accuracy and dependability of the system. Sensors have improved greatly in accuracy and longevity in recent years as well as decreasing in costs in 10 years this may lead to new sensors that could greatly improve the overall system. By allowing for revision to implement these new sensors will also allow the product to keep up with market demands. By this time the ability to cooperate with other companies may lead to working with high end athletic footwear companies and allow the embedding of sensors into footwear making the system more inclusive and less of an add on product. Making the product smaller and more efficient will allow the system to be more compact and make the sensors more secure.

By 15 years time the product will have underwent 2 revisions and after such a rebuild with added features may be needed to keep the product competitive in the market place. Expected features to be added range from a mechanical system to respond and physically intervene to dangerous movements, to using lighter products and materials to try and reduce the impact on the athletes performance. This complete rebuild may also allow for re-banding or diversifying allowing for a lower end and cheaper product for athlete's in those markets.

In 20 years if computer power continues to progress at the rate it is now then a completely new computation system may be a better option. Advancements in motion tracking may lead to it being an option as tracking multiple athletes during play is currently very demanding. But as this computational power is becoming cheaper this may be an option moving forward, another option when brainstorming may be to develop a sublimity system to support the ankle joint as while as the knee. If that were to happen a specialized system to sports may be an option such as a neck sensory system in football or an elbow system for tennis.

8 Design Defense

The overall design of this device is to accurately detect unsafe movements of athletes during athletic performance to help decrease the number of performance inhibiting injuries that can occur around the ACL relating to partial and full tears.

8.1 Primary Function

The main function of this device is to detect movements of the tibia relating to the femur of the lower leg in athletes the moment an unsafe movement occurs. These unsafe movements relate to the unnatural shift in the leg potentially stretching or tearing the ligaments of the knee. Approximately 350,000 ACL reconstructions are performed annually with full and partial ACL tears with athletes[62]. Athletes with previous knee injuries have about an eightfold increased risk of suffering a second knee injury within their career leading athletes to spend 50% more time in recovery than athletes suffering from other sports related injuries[62]. It has been approximated for 10-27% of ACL injuries are partial tears that go undiagnosed [63]. Currently there is no definitive test to prove a partial tear or rupture of the ACL has occurred while a complete ACL can be easily diagnosed [63]. Diagnosing a partial tear is a challenge although it is one of the most common sports injuries for both professionals and amateurs [64]. This device actively monitors the lower leg of any potential tears that could have occurred while twisting the knee, jumping or landing on a flexed knee, suddenly stopping or being hit [64]. This information obtained analyzed the amount of force exerted at once to see if the force is safe or potentially dangerous. Currently there are various knee braces that support the knee but none that monitor the knee forces itself. This will allow in observing more forces around the ligaments supporting the knee for potential detection methods of ACL tears and ruptures to decrease the number of new and reoccurring injuries.

8.1.1 Calculations

The most important problem that needs to be solved is how to translate an external force on the leg to an internal force on the ACL. This can be achieved by investigating the moment about the femoral head, and finding the stress acting on the joint. To determine how the force on the ACL changes based on the angle of bend of the knee, the knee joint can be modelled as a two member system and kinematic and dynamic equations of the system can be analyzed. Once the forces acting on the ACL have been evaluated, a force threshold can be determined for the device to detect.

Once the force threshold has been found, the circuit board can collect information from a pressure sensor that fits in an athlete's shoe and and a flex sensor that will fit in the actual knee sleeve. The pressure sensor in the shoe will communicate using Bluetooth to the flex sensor circuit on the knee to calculate how much force is being exerted on an athlete's knee at a given time. The main circuit on the knee will be able to communicate via Wifi to a bystander on the sidelines that will send notifications when a player has crossed the determined safe threshold.

8.1.2 Information

A pressure sensor embedded in the shoe will be able to determine the force of the step that the athlete exerts on their leg when walking. The flex sensor on the knee will be able to determine how much an athlete's knee is bent. Using these two measurements, the amount of force on an athlete's ACL will be able to be calculated. Using Mechanical force analysis, a force threshold for a dangerous movement has been determined to be approximately 1500 N. Once that information has been acquired by the sensors, the information can be processed by the microprocessor and transmitted to the coach receiving information on the sidelines. If an athlete has passed the allowable force threshold, the coach will receive a notification, and will be able to make a decision to remove a player from a game in interest of their health. A compression knee brace will be covering the knee, which is housing the main microprocessor. The main material used within this brace will be a knitted elastic fiber that will be able to be used in addition and under regular knee braces that are used for protection. This compressive brace will be worn continuously during sporting activities. The compressive brace's elasticity will allow the brace to stay in place. Knitted fabrics allow for support, high breathability, and the prevention of skin irritation. The knitted fabric in use will be a commercial PS-K with an area density of 613.33 g/m^2, thickness of 1.98mm [60]. This material has tensile properties in both the vertical and cross sectional direction which can be seen in Table 4.

8.1.3 Mechanical Analysis of the Knee as a 2 Member System

In order to create a accurate model of a human knee the Tibia and Femur were considered as members as the structure of a bone will transmit forces that will cause the ACL to break. The ACL is modeled as a soild body connecting the two members at a ridged angle. With spring connections (defined to only effect the system in tension) in the position of the PCL and MCL. The angle of the members is then systematically changed along with the solid model of the ACL in correlation with the research obtained.

By using the process to create a model it was able to accurately determine the effects on outside forces on the knee joint while in different positions. The forces applied were to the Anterior, posture, medial and lateral sides of the Tibia in turn. A torsion moment was then applied both Clockwise and counter clockwise to the tibia. All forces were applied 100 mm below the knee joint in correlation to where the senors will be in our design would end. In particular we were interested in how the bend angle of the knee, the valgus angle and the anterior distance/displacement of the Tibia from the Femur affected the rupture forces of the ACL

Through this modeling it is able to be concluded that there are multiple almost linear relations between bend angle of the knee and the rupture force of the ACL. The Medial and Lateral forces needed for ACL rupture during knee bend testing showed that damage would be done to the LCL or MCL while before the ACL is affected. When a torsion force is applied to the tibia it is also the LCL and MCL that will be damaged before the ACL, although if enough torsional force is applied to rupture the LCL and/or the MCL the ACL will be put at risk. If the LCL or and/or the MCL rupture from such a force our device has no way of detecting this damage and by extent protecting the ACL at this time.

See Table 2 for the complete data set of the anterior/posture forces that caused the model to rupture. It is these values with a factor of safety that the device will be designed to protect against through detection.

8.1.4 Circuit Design

The main goal of the circuit is to collect information that is required by the algorithm created to detect danger. The application consists of two circuits that communicate together using an SPI interface. Both circuits are powered by a chargeable battery. Hardware was implemented to charge these batteries and notify the user when battery levels are low. The first circuit will be placed by the knee. This circuit consists of a gyroscope, a sensor that reads the X Y and Z directions, and a flex sensor that reads the angle of the knee. The main objective of the first circuit or in other words the master is to collect data from the second circuit or the slave, and store the data into the Arduino chip for analyzing. Algorithms will be implemented into the ATMega chip (arduino) and collected data from all 5 sensors will be used to notify the coach if a wrong movement was committed. The Master circuit will communicate results with the coach through wifi that is provided by the ESP chip. ESP chip provides wifi communication with the user interface which is an application that the user can download through app store or the play store making it available on all platform. Coaches can download the application on their IPad and monitor their athletes. The second circuit will be placed by the foot. This circuit consists of 2 pressure sensors and a flex sensor. The main objective of this circuit is to collect information using the pressure sensors and the flex sensor, and provide the master circuit with the information needed for the algorithm to detect any injuries.

8.1.5 Circuit Board Communication

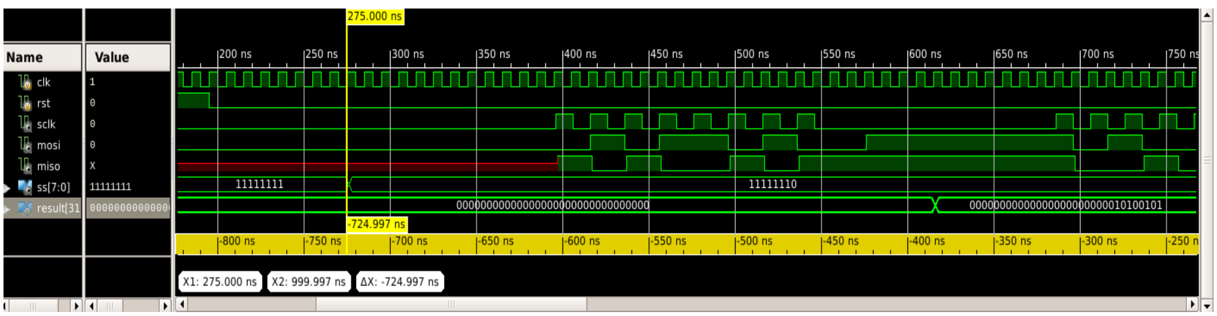

Figure 7: Communication Simulation

SPI communication will be used to transfer data from the master circuit to the slave circuit The Serial Peripheral Interface (SPI) bus is a synchronous serial communication controller specification used for distance communication, primarily in embedded systems. The SPI is a four-wire serial bus that communicates using the MOSI (Master Output, Slave Input), MISO (Master Input, Slave Output), SCLK (Serial Clock), and SS select (Slave Select). The waveform above was simulated to explain how IC chips will communicated together in this design. Data transmission begins on the falling edge of SS, then a number N of clock cycles will be provided. For this project a 16MHz clock cycle can be used, corresponding to the crystal clock implemented on the master circuit. The MOSI is driven with the output data payload. The data payload can contain either data and command. If MOSI contains a command, i.e. read command, after a programmed number of SCLK cycle, MISO will be driven with the serial data value read from the slave. This is how both circuits will send information. The SPI communication will be initiated by the ESP chip

8.2 Safety

Determining parameters of the system was done by first taking a biomechanical approach and calculating maximum allowable forces exerted on the ACL from the femur and tibia. Mechanical analysis was done to ensure a safe allowable stress was calculated the ACL can withstand without causing injury to the individual.

8.2.1 Compressive Brace Component

Knee braces overall are considered very helpful tools against the amount of force applied onto the ACL[65]. Knee braces aid in reducing knee flexion, abduction movement and adduction moment without impacting against athletic performance[65].Compression braces overall enhance blood and oxygen circulation to enhance energy movement enhancing overall athletic performance[66]. The compressive sleeve portion of the design is safe with added calculation of the extent of allowable compression based on the diameter of the lower leg being accounted for. Additionally the material itself is made of a knitted elastic fibre that can be prone to allergic reactions the material itself will include polyester that can cause skin tenderness and rashes if the individual wearing the brace is allergic to the additives of the material. Overall a very small percentage of individuals have adverse reactions as formaldehyde finishings and chemical additives will be avoided to prevent such allergies[67].

8.2.2 Electrical Components

This device is classified as a Class II Medical device as specified by the FDA regulations [61]. This device is actively monitoring and tracking users motions based on the sensors included with this device.Other codes and regulations what have to be followed include the Acceptance of Electrical Equipment in Canadian Provincial and Territorial Jurisdictions through the Electrical Safety Authority for the electrical components, ISO 14971 and IEC-60601-1-1 for risk management standards within electronic medical devices. These codes and regulations ensure the device will not cause any harm to the user or those within the vicinity.
Within the design of the device itself a 3.3 V battery will be used producing a current of less than 1 milliamp. 1 milliamp is the lowest current output an individual can feel similar to a faint tingle [68]. The battery itself used in conjunction with the sensors does not pose any safety hazards to the athlete wearing the device. For added protection all wires and sensors will be coated in a waterproof and restive plastic coating for added safety and protection. All of the frequencies emitted from the device will not interfere with any frequencies from other electronic devices. Force sensors are also integrated within the shoe of the athlete for measurement purposes. All of these sensors must be placed in such a way so accurate data measurements can be taken. Comfort of the individual must also be taken into account for the device not to be detrimental to any athletic performance.

8.3 Economic Defense

8.3.1 Economic Defense Preamble

Below is a detailed breakdown of the costs to produce, calibrate, transport, and maintain the final design of the knee brace. The costs of materials was a major contributor to the economic viability of the product. Further, manufacturing expenses, and business costs such as utilities, office supplies, shipping and handling, and insurance were considered.

Based on the information above, an economic viability break-even analysis was performed to determine the minimum price to sell the brace per unit and the number of units that need to be sold per month to break even. Relevant economic information needed to understand the economic defence, but not necessarily related to the economic viability of the brace can be found in Appendix C.

8.3.2 Capital Costs of Design

Because of the ongoing nature of the business, there will be a lot of recurring costs, in fact, most of the costs of operating a manufacturing system will be recurring. This minimizes the capital costs, as costs that happen periodically do not count as capital costs.

However, the one important capital cost is in the purchasing of manufacturing equipment. Machines needed to create the fabric sleeve will be needed, as well as to integrate the sensors, PCBs and wires to the brace. This will be the most important, and only capital cost, valued as \$7500.

Also, initially, the first month of payroll and materials will be counted as a capital cost. The first month's pay will be \$10000 and the first month's worth of materials (assuming approximately 250 units are made in the first month to break even) will cost \$4250, but after the first month, the cash flows will happen according with revenues from sales as well, and ten they can be treated as a periodic cost.

8.3.3 Lifetime Maintenance and Operation Costs

Contrasting to the small amount of capital costs, there are many ongoing costs for maintenance and operation. These include rent, electricity, employee payroll, office supplies, machine maintenance, shipping and handling of the finished product, a manufacturing cost per product, a cost for each printed circuit board, an insurance for the business. Details for each operation cost will be expanded upon below.

Renting an industrial property will be necessary for the production of goods. Because it is assumed that the manufacturing will happen in the Greater Toronto Area, renting a property in Toronto will be investigated. It was found that to rent an industrial property in Toronto, it approximately costs \$1/ft^2 **??**. It was also assumed that for the business requirements, approximately 10,000 ft^2 will be required for manufacturing and for office space, and as a result, \$10,000 was allocated for rent each month.

A similar argument can be made for electricity costs from Hydro One. Based on the property size and location, the cost per month of electricity was found to be \$1492.13 [24]. Without electricity, the business will have no hope of being productive, and as such, electricity is a necessary expense.

Another necessary expense is the payment of employees, as if the endeavour does not have people putting in effort to produce product, there will be no production. It is assumed that for all the employees in the manufacturing process and business, \$10,000 will be paid out monthly.

Office supplies are another cost that has been accounted for. This can include computers, phones, paper, pens, and the phone bill and the internet bill. As it is tough to quantify a precise amount for everything, \$500 monthly is assumed to be the total cost of office supplies needed.

Another monthly cost of business is insurance, to ensure that any potential damages, if they happen, can be mitigated and mediated. As it is another tough number to quantify, it is assumed that insurance costs will be \$2000 monthly.

The final group of cash flows that happen periodically are all the costs and revenues that happen as a per unit basis during manufacturing. For each knee brace manufactured, the materials needed to produce the brace will cost money. It was found that materials will cost \$5 per unit. Furthermore, as manufacturing printed circuit boards will need to be outsourced, that cost is not in control of the manufacturing process. However, the cost of manufacturing a printed circuit board is variable from the provider that was selected [35]. Calculations for the price per circuit board can be found in the appendix. Another cost associated with each unit is the manufacturing cost of each unit made. It was assumed that the cost of each unit's manufacturing will be \$35. Finally, the revenue made from each unit will need to be found. It was found that the cost per unit to break even was \$358.75, including sales tax.

8.3.4 Economic Feasibility Analysis

Based on the Break Even analysis in subsection C.2, the cost of one brace will be \$171.55 to break even, and 146 units will need to be sold monthly to break even. Based on the target market of semi-professional and university athletes, this is a margin that is completely attainable. The target market are athletes at this level, playing Volleyball, Basketball, and Football. Taking into account the University of Guelph's varsity rosters as a typical size for university team sizes, information can be gathered about the size of the target market for the brace. There are 105 players on the Men's Football roster, 16 on the Men's Basketball, 19 on the Men's Volleyball, and likewise 16 on the Women's Basketball and 18 on the Women's Volleyball. In total, 174 players are in the target market at the University of Guelph, for a total of 348 potential units to be sold (1 for each knee). This size is completely attainable to sell to, as many players of these sports wear knee braces as a precaution, rather than a necessity for their health. To expand on the target market, it is very easy to market to sports of lesser risk, such as Soccer of Field Hockey. Doing so would sell more units, earning higer revenues.

Furthermore, the price of each brace is certainly reasonable for the alternatives that are available for purchase. Many high-end knee braces can cost upwards of a few hundred dollars, and may range to one thousand, so a break even cost of \$171.55 is easily attainable, even with a hefty markup. Adding a markup only increases profits.

The break even analysis shows that investing in this product is a lucrative opportunity due to the budget that many semi-professional sports teams have for protective equipment for their players, the high amount of money that players are willing to spend on their protection, and the large number of potential players in the target market.

8.4 Environmental

One of the main advantages of this device is due to the easy integration of this knee brace with the current existing braces. This brace is to be integrates with the current ACL braces eliminating the need to overproduce completely new knee braces

This brace can be used with the current manufacturing facilities as no additional fabrication methods need to be implemented. This minimizes production costs along with the need to develop and build new manufacturing facilities. When designing the final knee brace, simple and easily available components were chosen to ensure a product that cn be manufactured easily.

8.4.1 LCA

A life cycle analysis(LCA) was carried out on the knee brace itself splitting up the knee brace into 2 systems, one being the cloth component itself, while the other component would be the sensors used. The LCA is based off of one knee brace. With this information the only variables remaining constant will be transportation emissions. The emissions associated with the knee brace itself will be based on the units produced. Below is a table listing the emissions associated with the current knee brace model. A more detailed brakdown of each component can be found within the appendix.

Figure 8: CO2 emissions created by the design and manufacturing process of the knee brace

Figure 9: Major contributors to a negative environmental impact

8.5 Social

8.5.1 Economic

ACL injuries are very costly to an individual relating to both lifetime surgery and rehabilitation costs that impact society.It is estimated the mean lifetime cost to society for a typical patient undergoing ACL surgery will occur costs of approximately $38,121, while those seeking rehabilitation occurred costs of around $88,538 [69]. This shows how the lifetime treatment of ACL injuries can be substantial to society, therefore more preventative measures must be explored to minimize these costs.

8.5.2 Physiological

Not only is an ACL tear expensive it also can have a negative physiological impact on the athlete injured. Many physiological factors can contribute to an athletes reluctance to return to the sport including a fear of re-injury, decreased confidence negatively affecting performance as well as stress and anxiety based on their physical condition[70]. Ensuring more safety measures are put in place monitoring athletes safety during performance with an additional device can help provide a sense of security to decrease the negative physiological effects.

9 Risks and Uncertainties

9.1 Uncertainty and Approximations

One potential issue with the calculations in the approximations make in attempt to make a universal model applicable to everyone. The approximate size of a 21-year-old male football athlete was used to decide the dimensions of the brace. This could be problematic for smaller athletes who want to use the device, as an incorrect fit could cause the device to perform incorrectly and not serve the intended purpose. One potential solution to this will be to create additional models in the future with more diverse dimensions, providing the opportunity for all athletes to protect themselves during their game.

In addition to this, the maximum ACL force was approximated to be 2000N, with the length width and thickness of the human ACL being approximated based on results found in credible scientific literature. An issue with this is that not everyone's ACL is the same. To try and mitigate possible injuries from such inaccuracies, a safety factor of 33% was implemented into the device to ensure a reduction in potential errors when working with athletes of different builds, genders, and ages.

9.2 Limited Market

The ACL injury detection system is specifically targeted towards high-calibre athletes. The team is currently in communication with leagues such as the NBA, NFL, and MLB, to discuss the potential of providing these to athletes to prevent injury. One potential issue that is inevitable with this, however, is the limited number of potential clients. If leagues do not decide to use the ACL injury detection system, there will be few potential alternative clients. One way to counteract this potential problem will be to also contact different post-secondary institutions that have competitive high-calibre athletes. This secondary market has the potential to be an essential supplementary to sports league bulk purchases, otherwise sales will be dependent on few potential clients and potential cash flow issues may be encountered during the off-seasons when leagues are less interested in purchasing the product or ordering replacements.

9.3 Potential Competitors

Another potential issue for the team is emerging competitors that develop comparable to the ACL injury detection system. Although the design itself can be patented to avoid intellectual property theft, other companies will be allowed to develop a unique system that accomplishes the same task as the team's system. If a hypothetical competitor is already established in the field of athletics and medical devices, they will have the advantage of already possessing a positive brand to potential clients, further limiting the refined market.

To minimize the potential of such a scenario occurring, the team is establishing several partnerships before the product will be officially announced and distributed. By making partnerships with well known leagues and institutions, the team will have the opportunity to establish a strong brand name before potential competitors could design, refine, develop, and release a consumer-ready product.

10 Conclusions and Recommendations

The Knee brace is a design that provides an alert system which notifies professional sport coaches when their players are prone to knee injury. A knee injury such as a torn ACL can prevent an athlete from performing in his career. Such injury requires at least 1 year of rehab. This is a problem that can be financially demanding as the rehab cost can range from \$160,000 to \$180,000. The rehab's main objective in this case is to make sure that the athlete gets back on the field as soon as possible with maximum performance and minimum fatigue. The designed solution solves such problem by providing coaches with information of knee status of every player on the field. The coach is notified when a faulty mechanic during a dynamic movement is detected by one of the players. Such information allows the coach to pull the player off the field and prevent a further or more serious injury from occurring. This solution is relevant especially in competitive sports.

When players are on the field in a competitive scenario, the adrenaline rush from the competition prevents the player from understanding how dangerous a faulty mechanic can be as pain threshold increase during that adrenalin rush.

The knee brace communicates with coaches on the sideline through a graphical user interface that can be downloaded on current technology. Communication is completely wireless making the design feel natural when brace is applied on the knee. The Knee brace is estimated to reduce the rehab cost by 60% -100% of the estimated cost mentioned above. This depends on how serious the injury is and how fast the coach reacts to injury after being notified.

The design consists of two different system that communicate together using Bluetooth to run an algorithm that detects when a knee is in danger. Specific variables are required to make the designed algorithm to work. These variables are calculated using a gyroscope sensor, flex sensors, and pressure sensors. The system is battery powered and can last up to 24 hours when fully charged. Safety is a key aspect in the design of the system as the design is completely waterproof and electrical components are isolated protecting the user from danger.

Through the life cycle analysis of the design, it was estimated to produce a product impact of 1180 kg of Carbon Dioxide during the lifetime. This impact is mostly caused by the batteries used to power up the system as batteries are not environment friendly.

The Knee brace system addresses the problem of knee injury such as an ACL tear, and the methods of reducing chances of insure. However, there are various ways the knee brace can be improved for optimal benefit and performance. One recommendation towards the design of the system is expanding the scope of such project by developing a method that prevents the ACL from tearing rather than just detecting false mechanic movements. Such recommendation can be achieved by using thermoplastics to prevent the knee from moving out of place through applying a current to the thermoplastic fibres. Applying current through the thermoplastic fibres contracts the knee and prevents the injury from happening. The challenge in such approach is supplying the right amount of voltage to the system as the right time under a short response time. Another recommendation is finding the right placement of two subsystems in one brace rather than having a system in the shoe and a system in the brace. Design should still meet the criteria and scope of project. Such improvement would reduce overall capital, maintenance and operating costs since system would not get moulded into the shoe.

Appendix A Design Process

A.0.1 Alternative Design-KT Tape with Sensors

Description The general idea behind this design is to use disposable, elasticized, kinesiology tape where the sensors to detect knee movements are able to snap in place in the tape, once applied to the knee

A.0.2 Alternative Design-Tension Band

Description This design is based on the is to use a regular small knee brace that conforms tightly to athletes lower legs while it provides support on the lateral and medial side of the leg. Tension bands will be added to the design running poster and anterior to the knee (**??**). These tension bands will have sensors incorporated to detect how much the tension bands are in tension or compression. This detection method will allow the sensors to detect exactly when the knee has shifted too far medially or laterally as it runs over top the athletes knee.

Design Merits With the tension bands running over top and behind the knee this will give the sensors a quick and constant flow of information. With this design, the tension bands can be incorporated into many knee braces. Cost of tension bands is very low and can be easily replaced.

Design Limitations As the tension bands will be on the outside of the brace it has the potential to come in contact with other players and hook onto something. This will pull the band fully out of place providing highly inaccurate results. Tension bands are also prone to overstretching and must be replaced often.

A.0.3 Alternative Design-Full length Supportive Leggings

Full length leggings similar to athletic pants worn by athletes will incorporate sensors on the quadriceps, a tension knee brace for support along with 2 sensors on the knee brace detection motion and movement of the athletes femur and tibia. An image of the proposed design can be seen in **??**.

Design Merits This design ensures exact placement of sensors on the athlete without inaccuracies due to a knee brace or sensor slipping out of place. This provides an all in one solution to detect quadriceps activation during play while analyzing the location of both bones attached to the ACL. Quadriceps activation is greatest during landing, and understanding the force of activation of the quadriceps along with the sensors analyzing knee movements allows for the collection of athletes data.

Design Limitations As this device is a full lower body suit, ensuring a perfect fit from athlete to athlete may prove difficult. Every athlete has a different body ratio of leg width to leg length to knee placement. Optimizing sensor location to every individual athlete on a team will prove to be tedious. Comfort to athletes needs may be unsuccessful therefore the overall product may not be used. This product may be undesirable to those wearing additional layers of team uniforms. During summer sports additional thick layers, such as under soccer chin pads or football uniforms, can be undesirable.

A.0.4 Alternative Design-Metal Frame

This design is based off of current high performance knee braces, it would involve sensors placed throughout the aluminum frame of such bracing systems with the circuity and power being sealed in. A gear lock system would also be implemented to hold the knee in place should the system be triggered.

Design Merits The design would be very robust and durable being made of study material, with a constant sensor placement as they would be in a soiled body little to no calibration would be required. It would be consistent with current levels of protection to knee ligaments but given more information to coaches.

Design Limitations This system could easily become to heavy to be comfortably worn especially on the knee as the method of attachment is a tension system. It would also be limited to sports and activities that large metal knee braces are currently involved in, as its bulk could be limiting in different sports.

A.0.5 Alternative Design-Automated Cloth Brace

The general idea behind this design is to connect data from sensors and send to a micro controller where data is collected and shared with the coach wirelessly. This system will consist of 5 sensors, 2 flex sensors, 2 pressure sensors, and an accelerometer. a flex sensor and an accelerometer will be placed by the knee. This will give the acceleration in the x y and z and the flex angle. a flex sensor and 2 pressure sensors will be placed by the ankle. These sensors will provide the shank flex angle, and the pressure applied. A user interface will be created to provide user's height and mass. These variables will be used to calculate the total force applied to the knee.

Design Merits The hardware design will be embedded into a cloth brace. The cloth brace will provide protection to the knee and help in preventing the ACL from getting insured. This feature will be taken advantage of in the proposed design. The design will be lightweight and comfortable keeping the athlete performance high. Hardware includes tiny IC chips that will prevent a bulky brace. The durability of the design should last for at least one year as the IC Chips consume low power allowing the battery life to last for 1 year. This design is simple and easy to implement making it cost effective. Brace will be easy to use and install as all the player has to do is wear the brace. The brace will calibrate itself as the user inputs his height and mass. Water resistance is still one of the criteria that is weak for such design and still needs to be thought of. This design includes two modules that act as a slave-master which gets rid of the wired connection that affects the players comfortably when using the device.

Design Limitations Some of the design limitation includes waterproof ability. This comes in play when athletes play under rainy conditions where water may come in contact with the hardware pieces. Another limitation is the microcontroller housing and where the housing should be places. This may affect the comfortably criteria of the device. Another limitation is pairing the two modules. This limitation comes in play when an athlete uses a different slave from the one that is already connected to the master.

A.0.6 Design Evaluation

Table 3: Decision Matrix

Criteria	Criteria Score	KT Tape with Sensors	Tension Bands	Lower Body Leggings	Metal Frame Gear Lock	Cloth Brace	Knee and Foot Sensor
Lightweight	20	9	8	7	4	8	8
Durability	20	3	2	8	10	6	7
Cost Effectiveness	5	4	4	3	3	4	3
Comfort	15	7	6	7	5	7	8
Ease of Application	15	5	4	6	6	7	8
Water Resistance	10	6.5	5	5	8	4	6
Multisport Applicable	10	8	5	8	3	8	10
Enviromental Impact	5	3	2	3	2	4	3
Total Scores	*100*	*6*	*4.8*	*6.55*	*5.8*	*6.5*	*7.3*

Being lightweight is extremely important for this design, as an athlete will be unable to perform properly while wearing the proposed device. As a result of this, the lightweight criterion is heavily weighted in the decision matrix. Furthermore, in sports such as football, players can be subjected to large forces, or be put under repetitive stresses. Because of this, the design's durability is of high importance, and is reflected as such in the design weighting.

Athlete comfort is important because if a person is unwilling to wear an extra garment during sport, they will not wear it. Due to this, athlete comfort is weighed heavily in the decision matrix. Due to the same reasons, ease of application is also weighted heavily.

The design's versatility in other sports is another important factor to be considered, but not nearly as important as the criteria listed above, and thus is weighted at half of the weighting of durability and lightweight.

As the sports that this brace will be used for are most likely not aquatic sports, the ability for the design to resist water damage is not as important as other factors. However, the ability to withstand some water is important to ensure that sweat does not damage the components. This is reflected with a lower weighting in the decision matrix.

As the environmental sustainability is not a component of the problem being tackled, the impact on the environment of the product's life cycle does not need to be heavily considered. As a result, a low weighting is given.

Finally, the product will be marketed to professional and semi professional athletes who can spare money to ensure their health, so the cost effectiveness does not need to be weighted heavily. A low score is given in the decision matrix.

Appendix B Calculations/Modeling to support Design

B.0.1 Analysis of Compressive Force

The knee brace itself will produce a compressive force on the athlete wearing the device. This will produce tension that will be applied to the athlete. The pressure is given below.

$$P = \frac{T \cdot n \cdot K}{C \cdot W} \tag{1}$$

P = average pressure exerted on the leg (25mm/Hg)
T = Tension applied to the leg
n = number of layers (Assumed to be 1)
C = Limb circumference (cm)
W = Width of bandage (4 cm estimation)

B.0.2 Material properties

The maximum compressive force found to help improve venous circulation is 25mm/Hg[60]. This gives a base calculation for the allowable tension on the leg considering various average leg circumferences. This measurement provides comfort and stability to the athlete achieved by the brace.

Load Direction	Breaking Load (N)	Breaking Extension %	Modulus (N)
Vertical	453.4	43.6	169.9
Cross Sectional	109.4	484.8	4.37

Table 4: Material Tensile Properties of commercial PS-K knitted elastic material [60]

Appendix C Economic Calcultions

C.0.1 Economic Bill of Materials

Part Number	Name	Quantity	Cost	Description
1	Knitted Fabric	0.3m x 0.6m	$1.4	Material the knee brace will be made out of
2	Flex Sensor	2	$0.35	Calculates how much weight is applied
3	Force Sensor	2	$0.35	Calculates the angles of the foot
4	Accelerometer	1	$0.50	Calculates the X, Y and Z coordinates
5	ESP 8266	2	$0.50	WIFI Communication between boards
6	ATMega 8266	1	$1	Computes results using algorithm
7	Battery	1	$1	Supplies power to the PCB board
8	Design Casing	2	$2	Encases the PCB Board
9	Power Supply Chip	2	$0.5	Supplies the right amount of voltage

Table 5: Bill of Materials

C.0.2 Economic Assumptions

The assumptions made are based on current prices around the GTA. Individual parts are estimated bases on individual cost fees. These prices are subject to change based on location and time of production. For these purposes the following assumptions were made to provide a base cost for production and manufacturing.

1. Manufacturing will be based within the GTA
2. Average monthly electricity usage is 10,000 kWh costing \$1500 [24]
3. Required space for manufacturing and office space will be 10,000 ft^2. Rent approximately costs \$1/ft^2 [27]
4. Paying employees will cost \$10,000 monthly
5. \$500 is required for Office Supplies monthly
6. \$15,000 is required for Machine Maintenance annually
7. Insurance costs are \$2000 monthly
8. A Minimum Acceptable Rate of Return will be equal to an average personal savings account rate of 2%.
9. The cost per unit, for shipping and handling is equal to \$14.10 [28]
10. The cost per unit, of Manufacturing the product is equal to \$35
11. Buying the necessary machinery for manufacturing will cost \$7500 upfront.
12. The materials cost of the cloth sleeve, wiring, and anything else not related to the PCB is equal to \$5.

C.1 Present Worth of Costs and Revenues

To find the present worth of the initial cost of Machinery, financial ratios were used to calculate the annual worth of an indefinite annuity. Taxes were included, and the values for taxes were found from the Government of Canada [29]. The present worth of the first cost is the cost of the Machinery, all that is needed is to multiply by CTF, where P is the first cost, t is the tax rate, d is the depreciation rate defined by the government, and i is the interest rate [30].

$$PW(Machinery) = P(CTF)$$
$$PW(Machinery) = P(1 - \frac{td(1+0.5i)}{i+t})$$
$$PW(Machinery) = -\$7500(1 - \frac{(0.1)(0.02)(1+0.01)}{0.02+0.2)(1+0.02)})$$
$$PW(Machinery) = -\$6824.25$$

A similar method was used to calculate the cost of the periodic payments, of Rent, Payroll, Electricity bills, Office Supplies, and Insurance for the business. All of these are monthly periodic payments, so the form of the equation is the same for all of them, and the prices, tax rates, and present worth values will be listed below the equation. Each of the monthly payments needs to be converted to a present worth so it can be made an indefinite annuity. The variable A represents the monthly annuity amount.

$$PW = A(F|A, i, 12)(P|F, i, 1)(1 - t)$$

Table 6: Monthly Cost, Tax Rate, and Present Worth including Taxes

Monthly Item	Monthly Annuity	Tax Rate	Present Worth
Rent	-\$10,000	10%	-\$95,177.05
Electricity	-\$1492.13	Included	\$15,779.61
Payroll	-\$10,000	Included	-\$105,752.28
Office Supplies	-\$500	20%	-\$4230
Insurance	-\$2000	Included	-\$21,150.46

The annual annuity calculation is easier. For the annually Maintenance of Machines, the calculation is below.
$PW(Maintenance) = A(P|A, i, 1)(1 - t)$
$PW(Maintenance) = -\$15,000(0.98039)(1 - 0)$
$PW(Maintenance) = -\$14,705.85$

The Manufacturing, Shipping, PCB, and Materials costs are a little more challenging. For the purposes of a Break-Even analysis, the number of products is unknown. But the number of items sold is so that the present worth will be equal to \$0. In the following calculation, p is the unit cost of a PCP (the manufacturer chosen has variable cost, so the cost will need to be calculated), and n is the total number of products being sold to break even.

$PW(Unitcost) = (p - \$35 - \$14.10 - \$12 - \$5)n(F|A, i, 12)(P|F, i12)$
$PW(Unitcost) = (p - \$66.10)n(13.412)(0.78849)$
$PW(Unitcost) = (p - \$66.10)n(10.5752)$
The total price of the PCBs were found by asking the producer to give prices of different numbers of PCBs to see what the change in cost would be. The data for that is below.

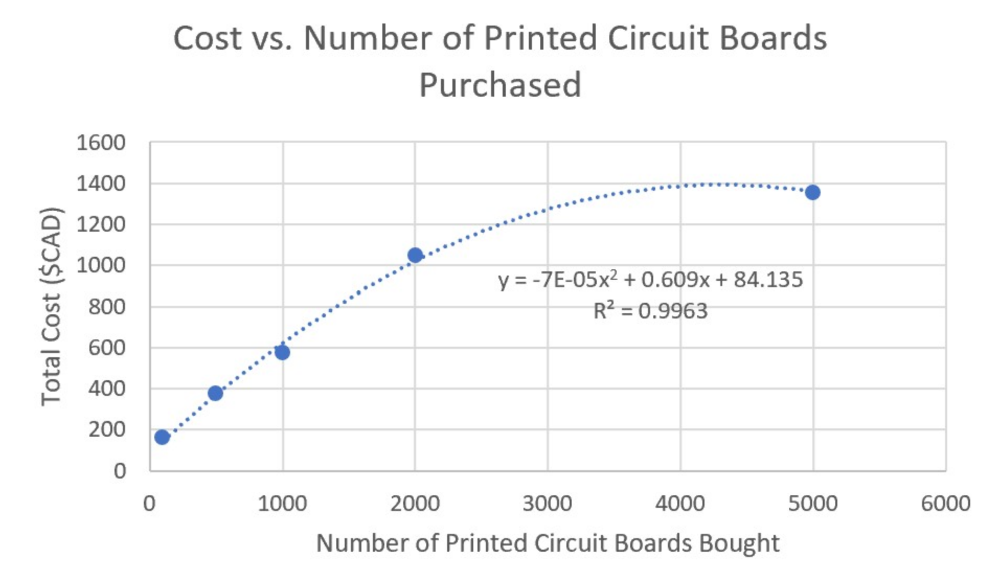

Figure 10: Total Price of PCB vs Number bought

The quadratic correlation gives the total price of PCBs with the equation:

$$p = -7 \times 10^{-5}n^2 + 0.609n + 84.135 \tag{2}$$

Where p is the unit cost of a Printed Circuit Board multiplied by the number of circuit boards bought.

C.2 Break Even Analysis

To determine the break even value, the number of units to be sold at a particular price is needed to be found. This can be found when the Present Worth is equal to zero. Substituting in the values found from subsection C.1, the break even calculation can be found below.

$\sum_{i=1}^{n} PW(i) = 0$
$-\$95177.05 - \$15779.61 - \$105752.28 - \$4230 - \$14705.85 - \$6824.25 - \$21150.46 + (p - \$66.10)n(10.5752) = 0$
$\frac{\$263619.50}{10.5752} = np - 66.10n$

Substituting in Equation 2,
$0 = -7 * 10^{-5}n^3 + 0.609n^2 + 84.135n - 24928.09$
Solving the equation using MATLAB, and disregarding values that do not make sense physically, the minimum number of units sold to break even on investment is 146.

Substituting the number for n into Equation 2, the price that each unit needs to be sold to earn back the principal investment is $171.55.

Appendix D LCA for each Component of the Knee Brace

Assembly name: cloth brace

Part name	Material	Part mass	Qty	CO2
casing	ABS	0kg	1	0kg
Material:	ABS			0kg
Disposal:	0% recycled, 100% landfilled			0kg
Knitted fabric	Polyester fabric	0.5kg	1	1.93kg
Material:	Polyester fabric			1.93kg
Disposal:	0% recycled, 100% landfilled			0.00667kg
Totals:		0.5kg		1.93kg

Figure 11: LCA analysis of the cloth brace

Manufacture and Disposal
Assembly name: sensor

Part name	Material	Part mass	Qty	CO2
accelerometer	PCB board only	0kg	1	0kg
Material:	PCB board only			0kg
Disposal:	0% recycled, 100% landfilled			0kg
battery	battery, lithium	0kg	2	0kg
Material:	battery, lithium			0kg
Disposal:	0% recycled, 100% landfilled			0kg
pressure sensor	resistor, general	0kg	2	0kg
Material:	resistor, general			0kg
Disposal:	0% recycled, 100% landfilled			0kg
integrated circuit	PCB board only	0kg	3	0kg
Material:	PCB board only			0kg
Disposal:	0% recycled, 100% landfilled			0kg
flex sensor	resistor, general	0kg	2	0kg
Material:	resistor, general			0kg
Disposal:	0% recycled, 100% landfilled			0kg
Totals:		0kg		0kg

Figure 12: LCA analysis of the sensor components

Product Use

Consumables

Consumable	Details	CO2
AAA BAttery, lithium-ion	300 AAA Battery per Year	1170kg
Totals:		**1170kg**

Power

Power	Details	CO2
battery	100 Hours per Year for a total of 1 Year	0.102kg
Totals:		**0.102kg**

Figure 13: LCA analysis of the consumable components

Transport

Transport name	Assembly Transported	Mode	Distance	CO2
shipping	Final Assembly	Air freight, intercontinental	9000 km	4.81kg
shipping	Final Assembly	Rail freight	500 km	0.0099kg
Totals:				**4.82kg**

Figure 14: LCA analysis of the transport component and emission production

Appendix E Project Management-time spent and cost of design

E.1 Project Gantt Chart

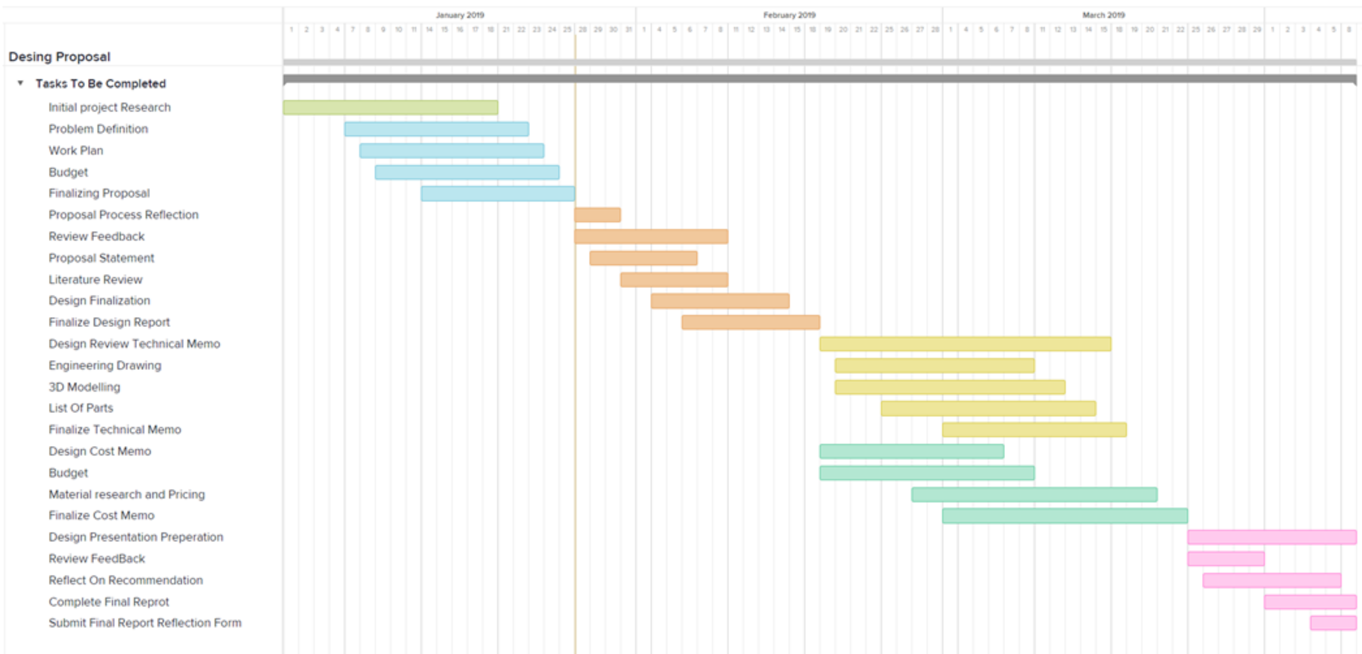

Figure 15: Project GANTT Chart

E.1.1 Initial Project Research (Jan 1st - 18th)

A total of 45 man hours were invested into the research of this project this ranged from looking into relevant Patents, Technical Articles and Trade Journals as well as spending considerable time using the Internet resources and Consultants that were available. All members of the design team were asked to complete their own research and bring the relevant information that they found to the first meeting outside of in-lab. As such each member was able to contribute to the discussion of how to approach this problem.

E.1.2 Problem Definition (Jan 7th - 22nd)

A total of 5 hours were invested into creating a detailed problem definition and by extent problem statement. By defining a solid and detailed problem statement to refer to later, ideas and concepts considered beyond the scope of this project were eliminated before too much time was invested in them.

E.1.3 Work Plan (Jan 8th - 23rd)

No defined amount of time was spent of defining a work plan as it is a continuously evolving entity as team members are able to take and give suggestions as needed to complete the project in a quality and on time manner.

E.1.4 Budget (Jan 9th- 24th)

Due to the nature of this problem and the corresponding design the cost of the design is not as significant. Being marketed to high performance athletes and leagues means that the final cost of the product may be high to the lay person but relatively low to these individuals, especially if it is to protect their physical assets. As such, creating this product as a start up companies first product is not feasible to bring this design to market.

E.1.5 Finalizing Proposal (Jan 14th- 25th)

In order to produce a quality proposal many different concepts of solutions were created with 40 hours spent both in group meetings and individually. After concept generation, the workload for completing the proposal was then split among the design team. In order to complete some of the larger task members worked in smaller subgroups, specifically almost perfectly breaking off into groups by major.

E.1.6 Proposal Process Reflection (Jan 28th- 30th)

Looking back upon the completion of the design proposal the design team should have allotted more time for the entire team to read through the report and make the necessary edits and additions to each others part. As the completion of the report was rushed this time was extremely limited and the cross editing was lacking. As such this was brought up in the next design team meeting as a priority for the inter min report.

E.1.7 Review Feedback (Jan 28th- Feb 8th)

After taking into consideration the feedback given by our TA, the main focus for the next report being the interim report was to create a very specific and easy to read report. As such the use of the software Latex was implemented to create a very detailed and organized report that all members could edit simultaneously.

E.1.8 Proposal Statement (Jan 28th- Feb 6th)

The proposal statement was used as a claim that outlines the problem addressed by this report. The statement of the problem addresses ACL injuries and how to prevent them.

E.1.9 Literature Review (Jan 31th- Feb 8th)

the literature review summarizes and explains the complete and current state of knowledge on "The prevention of ACL injuries" that was found in academic books and journal articles.

E.1.10 Design Finalization (Feb 4th- Feb 14th)

Over 34 hours were put into the finalization of the design, with both a decision matrix and sensitivity analysis being implemented to give quantifiable data to the selection process the design of having two independent parts (one on the knee the other in the shoe) working together in one system became the clear front runner. As such more time was spent in fleshing out the details and working through potential issues than for other designs.

E.1.11 Finalize Design Report (Feb 6th- Feb 18th)

Completing this report ahead of time was extremely important to the design team as avoiding the stress and pressure associated with last minute time frames cause. By meeting frequently in the weeks leading to the due date of the report self imposed soft due dates were created and held too. Through this process the creation of a more accurate and detailed report was created and it is a process that the team is likely to implement moving forward.

E.1.12 Design Report Technical Memo (Feb 19th- Mar 15th)

The technical memo is designed to effectively review project and experimental details of the solution proposed in this report.

E.1.13 Engineering Drawing (Feb 20th- Mar 8th)

The engineering drawing present a visual representation of the solution proposed in this report.

E.1.14 3D Modelling (Feb 20th- Mar 12th)

3D modeling was used throughout the design process, in the beginning Soildworks FEA was used to determine what forces are acceptable for an ACL to experience before our design should intervene. After which modeling a rough idea of the final design was used to help to keep the team on the same page. By adding more details were added and problems were solved the 3d model was updated creating a accurate model of the expected design.

E.1.15 List of Parts (Feb 25th- Mar 14th)

The list of part report will highlight the parts used in this project. The main parts used will include a micro-controller, an accelerometer, 2 flex sensors, and 2 pressure sensors. This report will include the cost of overall system.

E.1.16 Finalize Technical Memo (Mar 1st- Mar 8th)

The team will finalize the technical memo report and make sure any new update in terms of designing the solution is reported .

E.1.17 Design Cost Memo (Feb 19th - March 6th)

The design cost memo report will include the cost of all components used to design the system described in the report. This report will go in depth into why components were used and cost clarification.

E.1.18 Budget (Feb 19th - March 8th)

The budget will be reviewed and edited to make sure report is accurate after design changes committed. New updates and costs will be reported depending on the changes made after finalizing the design report. The main goal of this report is to address the costs of implementing and designing the proposed solution to the problem statement.

E.1.19 Material Research and Pricing (Feb 27th - March 20th)

The main goal of the material research and pricing report is to provide a clear explanation of why the hardware components, materials, and tools were used. This will include the price of all components of the system described in the report. This report will be updated depending on any changes made later on throughout the project timeline.

E.1.20 Design Presentation Preparation (Mar 25th - Apr 8th)

During this phase, the team will get ready to present the solution provided in the report to the School Of Engineering. Preparation includes going over the report and ensuring all information is accurate and presentable.

E.1.21 Review Feedback (Mar 25th - Mar 29th)

Feedback provided will be reviewed and improvements to report will be implemented depending on the comments from the feedback. The feedback provided will help in perfecting the final report.

E.1.22 Reflect on Recommendation (Mar 26th - Apr 5th)

After reviewing feedback, the team will reflect on the improvements implemented into the report. All sections will be updated individually to make sure all sections correlate and accurately describes the solution presented.

E.1.23 Complete Final Report (Apr 1st - Apr 8th)

The team will proof read the final report and connect the final dots together making sure all sections connect in a professional manner. Any chances implemented into the design will be updated to make sure all information is reported in the final report. After team finalizes the report, the team will present the report to teacher assistants to collect minor recommendation to improve the final report.

E.1.24 Submit Final Report Reflection Report (Apr 4th - Apr 8th)

After proof reading and reviewing, The final report will be submitted.

E.2 Updated Resources Required to Create Design

The material of the knee brace must be made from a very lightweight and thin material.
A neoprene material for the material will be favoured due to its toughness and durability. This will allow for a lightweight, durable material. Anti slip silicone coating around the perimeter of the device ensures no slip during exercise while ensuring minimum error from a moving device measuring incorrect movements @ flex sensors will be incorporated to measure the angel of the knee and the flexion/ extension angle of the ankle. 2 pressure sensors incorporated into the soles of the athletes shoes to detect the ground reaction of the athletes either distributed on the heel or ball of the foot. 1 accelerometer will be added to the knee brace to continuously detect changes in motion.

E.3 Updated Summary of Costs

E.3.1 Define Problem

Table 7: Breakdown of Problem Definition

Activity	**Summary of Activity**	**Time Invested**	**Cost**
Problem Statement	What issue does this project solve	5 (H)	375 ($)
Bench marking	How a successful project is determined	5 (H)	375 ($)
Product Dissection	What are the important components needed for this project	15 (H)	1,125 ($)

E.3.2 Gather Information

Table 8: Gather Information

Activity	**Summary of Activity**	**Time Invested**	**Cost**
Internet	Used as a resource to determine our projects validity and comparability to existing models	23 (H)	1,725 ($)
Patents	Used as a resource to determine our projects validity and comparability to existing models	2 (H)	150 ($)
Technical Articles	Used as a resource to determine our projects validity and comparability to existing models	10 (H)	750 ($)
Trade Journals	Used as a resource to determine our projects validity and comparability to existing models	3 (H)	225 ($)
Consultants	Used as a resource to determine our projects validity and comparability to existing models	7 (H)	525 ($)

E.3.3 Concept Generation

Table 9: Concept Generation

Activity	**Summary of Activity**	**Time Invested**	**Cost**
Creativity Methods	Using techniques to create unique solutions	3 (H)	225 ($)
Brainstorming	Using teammates to create possible solutions	16 (H)	1,200($)
Functional Models	Creating quick models to describe a design detail	1 (H)	75 ($)
Decomposition	Creating a system to interface important components	20 (H)	1,500 ($)

E.3.4 Evaluation of Concepts

Table 10: Evaluation of Concepts

Activity	**Summary of Activity**	**Time Invested**	**Cost**
Decision Making	Team meetings to discuss options for next steps	12 (H)	900($)
Selection Criteria	Team meetings to discuss options for project evaluation	20 (H)	1,500 ($)
Decision Matrix	Used to give analytic value to subjective traits for project evaluation	2 (H)	150 ($)

E.3.5 Configuration Design

Table 11: Configuration Design

Activity	Summary of Activity	Time Invested	Cost
Preliminary Selection of Materials	Sourcing and evaluating possible materials	11 (*H*)	825 ($)
Modeling	Creating a detailed/working CAD model of design	25 (*H*)	1,875 ($)

E.3.6 Parametric Design

Table 12: Parametric Design

Activity	Summary of Activity	Time Invested	Cost
Robust Design/Setting Tolerances	Developing the production end of our design	7 (*H*)	525 ($)

E.3.7 Detailed Design

Table 13: Breakdown of Problem Definition

Activity	Summary of Activity	Time Invested	Cost
Engineering Drawings	Using CAD model to produce accurate drawings	12 (*H*)	900 ($)
Finalize PDS		35 (*H*)	2,625 ($)

Therefore the total amount of time being invested in the project is projected to be 180 Hours. With an average cost for a junior engineer in training of $75 per hour, an approximate cost of design is $13,500. This is not including all resources and tools used for design, so the final cost of design will be a slightly higher amount.

Appendix F Response to Feedback

F.1 Feedback from Design Proposal

- Identifies and discusses all the important aspects of the problem; strong justification of the need for the project
- Anticipate and explain needs and impacts in social, environmental, health and safety, and economic terms at least for client and immediate users
- Prepares an excellent literature review pertaining to the problem; Cites many high quality references (credible, reliable) to provide clear context for the project and strongly support justification

- Design objectives are clearly stated and define problem well; Scope of work reasonable
- Identifies and discusses the major constraints, criteria and assumptions; Problem is well defined
- Design process outlined; some missing details or weaknesses in proposed approach
- Tools to be used in development of the design only described in general terms or with weak justification
- Some key reference documents or obvious information required is missing; Some consideration for timelines required for gathering information
- Schedule provided. Some activities required to complete design or key milestones and deliverables missing. Responsibility and time assigned for some tasks.
- Good relation of fees to project activities and responsibilities. Proposal overhead costs included.
- Concisely summarizes key items; Appropriate language and content for a general audience; Appropriate length. organization that minimizes repetition and promotes flow throughout, Excellent transitions; Key report elements are integrated and mutually reinforcing.
- Paragraph structure is mostly logical; Grammar, punctuation and spelling errors are infrequent.
- Appropriate for the intended audience; Appropriate use of technical terminology, with definitions as needed; Jargon avoided; Strong non-technical word choices.
- Clear figures and formatting; Most aid the presentation; Professional quality.
- Necessary elements provided including professional letter of transmittal and title page. Citations and references are mostly complete and properly formatted. Appropriate appendices are included and referenced in the body of the report

F.2 Feedback from interim Report

- Identifies and discusses most of the important aspects of the problem; justification of the need for the project.
- Identifies and discusses most of the important aspects of the problem; justification of the need for the project
- Anticipate and clearly explain needs and impacts in social, environmental, health and safety, and economic terms beyond the client and immediate users.
- Prepares an excellent literature review pertaining to the problem and setting the stage for alternative designs; Cites many high quality references (credible, reliable) to support key points
- Design objectives are clearly stated and define problem well; Scope of work reasonable
- Identifies, discusses and justifies all constraints, criteria and assumptions; Problem is fully defined
- Identify and acquire information and data from multiple, credible, independent sources. Important standards and codes identified
- Describes strategies used for generating alternative design concepts/components, including some intended to stimulate creativity
- Describes a sound method for evaluating the alternatives and ultimately selecting the preferred concept/components

- Several distinct alternatives, including at least one novel idea, generated by applying idea generation strategies; Alternatives are described and include some feasible solutions
- Design ideas evaluated against constraints and some criteria and assumptions. Evaluation method is simplistic/ less objective, and rankings weightings are not well supported. Sensitivity analysis is basic.
- Design description is good, but not outstanding. Most of the main design features are highlighted and documented
- Well organized and complete representation of PM components, including schedule, resources, and progress related to budget
- Clear and logical discussion of project status related to completion. Challenges recognized with clearly communicated solutions (e.g. changes to scope, schedule etc.), as well as proposed strategies to minimize further risk to the project
- Summarizes most key items; Written for technical audience; Length is too short (missing some important points) or excessive (too much detail or lack of conciseness).
- Logical organization that minimizes repetition and promotes flow throughout; Excellent transitions; Key report elements are integrated and mutually reinforcing
- Paragraph structure is coherent and logical throughout; Very few grammar, punctuation, or spelling errors
- Final design decision is justified; Logical arguments made and are supported by evidence (e.g. decision matrices and sensitivity analyses); Report provides a defense that the selected alternative meets client/user needs and adds value for society/non-users
- Appropriate for the intended audience; Appropriate use of technical terminology, with definitions as needed; Jargon avoided; Strong non-technical word choices
- Flawless formatting; Clear, informative figures; Enhances presentation consistently; Professional quality. Excellent adherence to graphical standards
- All necessary elements provided including professional letter of transmittal and title page. Citations and references are complete and properly formatted. Appropriate appendices are included and referenced in the body of the report

F.3 Feedback from Technical Memo

- The purpose and value of the calculations are very clear. The calculations are critical for the larger design project and no important calculations are missing.
- Problem statement conveys the main motivation but could be improved with use of more appropriate engineering or non-engineering terms.
- Most of the information to solve problem is assembled, justified and properly referenced.
- Most of the important assumptions and necessary material properties are listed, explained and referenced.
- Correct engineering laws and principles are applied. They could be stated with more clarity or minor errors exist in their presentation.
- Execution of the engineering calculations suggests a minor lack of understanding of the technical topics or engineering codes, standards, guidelines and regulations.

- The engineering calculations are carried out with a few minor errors or inadequate attention to significant figures or errors and uncertainty.
- Results are stated. Critique and appraisal of the results is attempted.
- Calculations could be neater or more clearly communicated.
- References cited are not credible or reliable. Improper format.
- Technical Memo is laid out fairly well.

F.4 Feedback from Cost Memo Report

- The purpose and value of the calculations is clear and obvious. The calculations are critical for the larger design project. A conceptual framework is clearly formulated.
- The problem statement is vague or incomplete, but the main motivation is apparent.
- All of the important cost information to solve this problem are assembled and properly referenced including initial materials, labour, operation, and maintenance costs.
- Most of the important assumptions and necessary costs are listed.
- Appropriate economic principles are applied but minor errors and/or omissions in the initial economic model exist.
- Economic calculations are carefully executed demonstrating an excellent understanding of the lifetime economic conditions.
- Comprehensive analysis of the economic feasibility of the design based on the initial assumptions and the sensitivity to anticipated variations in the major assumption. The engineering calculations are carried out accurately.
- Results are somewhat unclear but there is an attempt to connect them to the project as a whole.
- Calculations are neat and clearly communicated.
- Cite some high quality references (credible, reliable) which support key points and calculations; Follows proper format consistently throughout.
- Cost Memo is professionally laid out and easy to read.
- The purpose and value of the calculations are very clear. All calculations important to the economic analysis have been included.
- Problem statement conveys the main motivation but could be improved with use of more appropriate engineering or non-engineering terms.
- All of the important cost information is assembled, justified and properly referenced, including initial materials, labour, operation and maintenance costs.
- Most of the important assumptions are explained.
- Appropriate economic principles are applied. Minor errors and/or omissions in the initial economic model.
- Economic calculations are carefully executed demonstrating an excellent understanding of the calculation procedure and lifetime economic conditions.

- Comprehensive analysis of the economic feasibility of the design based on the initial assumptions and the sensitivity to anticipated variations in major assumptions.
- Results are stated. Critique and appraisal of the results is attempted.
- Calculations are neat and clearly communicated.
- Cites some high quality references (credible, reliable) to support key points and calculations. Mostly follows proper format.
- Cost Memo is professionally laid out and easy to follow.

F.5 Feedback from design Presentation

- Prepared and on time for presentation. Some minor difficulties (e.g. technical issues) slow the presentation, but still within time constraint. Adapts to changes in schedule if needed.
- Appearance of team members is well coordinated and appropriate for the presentation. All team members are always attentive and engaged when it isn't their turn to speak. Body language enhances the presentation and effective positioning of team members is coordinated.
- Very engaged in other team presentations (i.e. asks thoughtful questions/provides very effective peer feedback) and supportive of peers (i.e. listens attentively
- Key messages evident. Conclusions consistent and substantiated. All relevant content is included, with minimal content that does not contribute to conveying the central message.
- Excellent structure. Comprehensive coverage of technical content. Easy to follow with smooth logical transitions between topics.
- Reasonable defense that design is good for the client and broader society. Technical evidence (see below) integrated into the defense.
- Good engagement of audience; Some group members are more engaging than others. Consistently clear voices and eye contact. Most visual aids add value. All team members participate mostly equally.
- Listened carefully to questions. Respectful of peers. Shared roles. Peers supplement responses when appropriate.
- Clear problem definition. Context and justification well articulated and supported. Clear scope. Comprehensive and clear constraints, criteria and assumptions.
- Good design process with some justification for design decisions. Some evidence of evaluation and iteration to refine design.
- Complete and detailed description of design, including engineering drawings. Well supported by appropriate analyses, simulation or other means.
- Excellent results/evidence provided to support discussion of design's ability to meet client/user needs; Clear technical basis provided for all stated claims; Very few technical weaknesses
- Good results/evidence provided to support discussion of design's health and safety, economic, environmental and social benefits/ impacts (beyond primary function/client needs

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