# Creating adaptive technology to play the piano

**Mid-Semester Report**

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**Client**

Vicki Janisch

Mary

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**Abstract**

AgrAbility of Wisconsin (AAW) supports Wisconsin farmers and their families by accommodating disability in agriculture and promoting disability awareness. Our client is Vicki Janisch who is an outreach coordinator for AAW. Her long time client is Mary, a Wisconsin farmer who has rheumatoid arthritis and as a result has had a below-the-knee amputation of her right leg in addition to bilateral knee replacements and left ankle fusion.

Mary's passion is playing the piano. Both of her ankles have little to no flexion, which prevents her from using the damper pedal that is necessary to create a rich, full sound. Some current adaptive devices exist, but are not ideally suited to our client's greatest need of portability. We developed three design options: the Wedge & Lever System, the Free Weight & Pulley System and the Translating System. Through analysis of the design matrix, which identifies and key design specifications, the best option was selected. The next step is to create and test a prototype.

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## Background

### *Client Description*

Our client is Vicki Janisch, an Outreach Specialist for AgrAbility of Wisconsin (AAW). Established in 1991, AgrAbility of Wisconsin is a partnership between the University of Wisconsin Cooperative Extension and Easter Seals Wisconsin. It supports Wisconsin farmers and their families by accommodating disabilities in agriculture and promoting disability awareness [1].

Ms. Janisch has known a specific client of hers, Mary, for quite a while. Mary has rheumatoid arthritis and has turned to AgrAbility before to enable her to continue farming even with this disease. Vicki, along with AgrAbility, have helped Mary before by providing adaptive equipment [2], and now she wants to help Mary some more. Vicki has requested an adaptive technology device that would enable her client, Mary, to return to playing the piano, a lost passion of hers since the onset of rheumatoid arthritis.

### *Current Devices*

Currently, there are a few different kinds of piano adaptation devices for people with disabilities; however, most of these devices are very specialized for the unique individual. Two devices were found that most similarly matched this project's design requirements.

The first adaptive device to play the piano found was developed at Duke University for a client who had a bilateral amputation. The apparatus, shown in Figure 1, created involves a wedge anchoring system and a series of levers. The device functions by lateral motion of the user's thigh. This motion pushes a mechanical lever horizontally which activates a series of levers that eventually converts the lateral movement into vertical movement and presses the pedal [3]. The user is able to control the amount of force applied by varying the amount of lateral motion. When the client moves the leg medially back to resting position, the pedal is released. This device proves to be portable and adaptable to any piano since it can be placed under any pedal and attaches using a simple clamp.

**Figure 1:** Thigh-controlled piano adaptation device created by Duke University [3].

The second device found was created for a comparable situation, and was designed by Michiel van Loon(www.pianoman.nl), who specializes in making piano pedals for clients with disabilities. His most recent device uses a pipette to control the force applied to activate the pedal. Figure 2 displays other components in this design [4]. This device is used specifically for clients who do not have control of their lower body. The pipette is placed in the mouth of the user, shown in Figure 3, and the act of squeezing the pipette activates the pedal. This action triggers a switch which activates the solenoid. As the solenoid moves, it actuates the pedal rods which depress the pedal. Although this device can be easily controlled, its main disadvantage is that it lacks be portability.

**Figure 2:** Components involved in the pipette design created by Michiel van Loom include a solenoid, control board, power unit, and pedal rods [4].

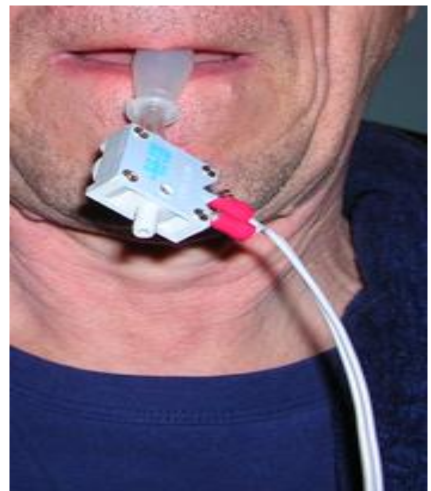

**Figure 3:** User presses down on pipette with their mouth to activate piano pedal [4].

Regardless of their restrictions, both devices enable clients with lower-body limitations to play the piano. Two important aspects of these designs include minimal force application and user control. These features will be taken into consideration throughout the design process of the adaptive device for Mary.

## Problem Motivation

Mary is a Wisconsin farmer who raises bull calves. She has been a client of AAW since 1993 [2] because she has rheumatoid arthritis (RA). According to the Center for Disease Control (CDC), an estimated 1.5 million people have rheumatoid arthritis [5], [6]. Unlike the more common, osteoarthritis, which is due to wear and tear, rheumatoid arthritis is a chronic, systemic, inflammatory disorder. The exact cause has not yet been determined, but once the inflammatory process begins, an autoimmune reaction perpetuates this chronic condition [7]. Figure 4 depicts a joint lesion and the commonly affected joints. These joints are warm, swollen, painful, and especially stiff after a period of inactivity, making simple daily activities excruciatingly painful [8]. To date there is no cure for this debilitating disease.

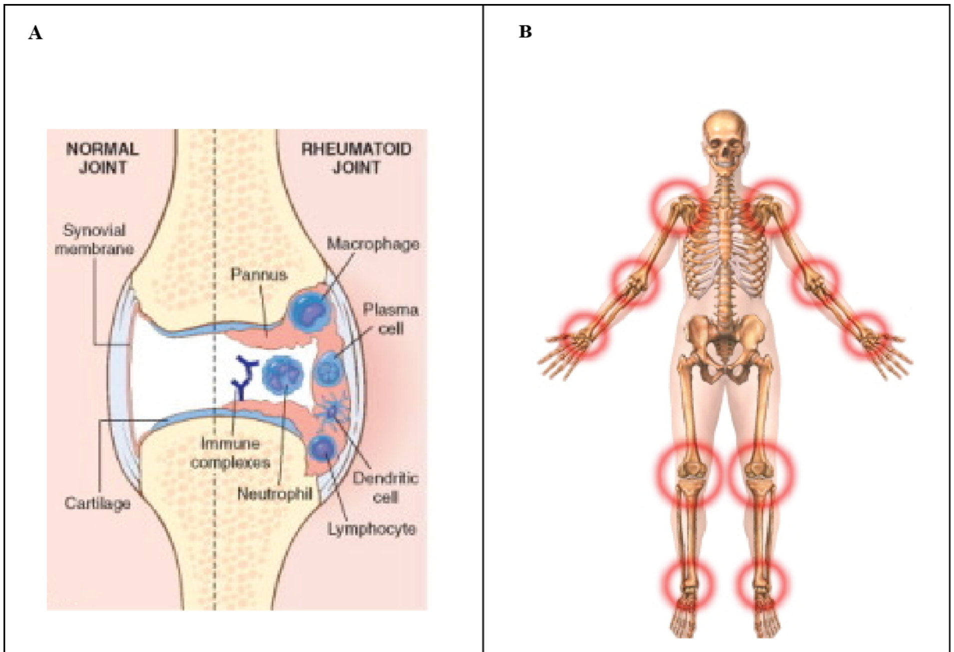


**Figure 4.** Rheumatoid Arthritis and Affected Joints. (A) In this figure, the left side of the joint is normal while the right side illustrates a joint lesion that resulted from the body's immune system attacking itself [7]. (B) While variable, the pattern of joint involvement in RA is typically symmetrical, with smaller joints being affected before larger ones [8].

Rheumatoid arthritis has greatly altered Mary's life, and makes her passion of playing the piano exceptionally difficult. This disease has resulted in two knee replacement surgeries, a below-the-knee amputation of her right leg, and a completely fused left ankle. Mary has been fitted with a prosthetic right leg which restores her ambulatory ability, but does not provide a natural range of motion. The lack of flexion in either ankle proves to be the most significant problem for Mary when attempting to play the piano because she is unable to apply the adequate force to the piano pedal. The goal of this design project is to provide Mary a device that enables her to play the piano again.

## Design Requirements

The design requirements outlined in the Product Design Specifications in the Appendix are explained in detail here. Requirements for this design revolve around three main focuses: client requirements, patient comfort, and safety.

The client requests a device that will allow Mary to play the damper piano pedal with her prosthetic foot. Due to limited range of motion, the device should not require the flexion of her ankle to operate. Within the physical and operational requirements, it was determined that the device needs to apply a minimum force of 3.63 kg (8 lbs) in order to depress the piano pedal. The device should be durable and able to withstand repetitive use (about 20 times per minute over an approximate five minute increment) and allow for varying force application. The size of the device should be small enough to fit under or between multiple piano pedals to satisfy the requirement of adaptability set forth by the client.

Patient comfort is another main concern in the design as Mary has limited range and types of motion that can be utilized to activate the piano pedals. The user should be able to easily activate the device with a controlled motion which will, in turn, depress the pedal. It should also not require much effort by the user in resting position, therefore the foot should be able to rest comfortably between pedal activation. The device should also be light weight, less than 15 lbs, and compact to optimize portability since Mary will need to move the device herself.

Safety is the third and final focus of our product design specifications. The device will be used by Mary directly, and should therefore pose no danger to her. The device will be in contact with the client's prosthetic limb, and should not affect its mobility or function. Additionally, the device should not contain any sharp edges or constricting pieces that may cause the user harm while using or transporting from place to place.

Client requirements, patient comfort, and safety are the three main points that our product design specifications are centered around. Keeping these design requirements in mind while designing and fabricating the final device will be crucial to ensure effectiveness and client satisfaction.

## **Design Alternatives**

Prior to building and testing, three design alternatives were conceptualized and evaluated based upon criteria set in the design matrix. All three designs were developed for the user to utilize the device in a seated position facing the keys of the piano.

*Wedge and Lever System*

The first design incorporates a wedge and lever system placed at the foot of the user, as shown in Figure 5. The wedge component houses the foot of the user and is attached to a gliding mechanism similar to that of a drawer. The gliding mechanism will provide ease of motion in the anterior and posterior directions. This motion consists of flexion and extension of the knee joint, which is a motion easily conducted and controlled by the user. Forward gliding of the wedge causes the wheels at the near end of the lever to roll up the wedge, and thus causes rotation about the pivot point at the end of the platform.  At the far end of the lever, a crossbar will be attached to the piano pedal to prevent slipping.  The forward motion of the wedge activates the lever motion downward, and applies the necessary force to depress the pedal.  A strap around the ankle of the client will enable her to pull the wedge back, which would lead to the wheel rolling back down the ramp, and ultimately releasing the pedal.

Side view:

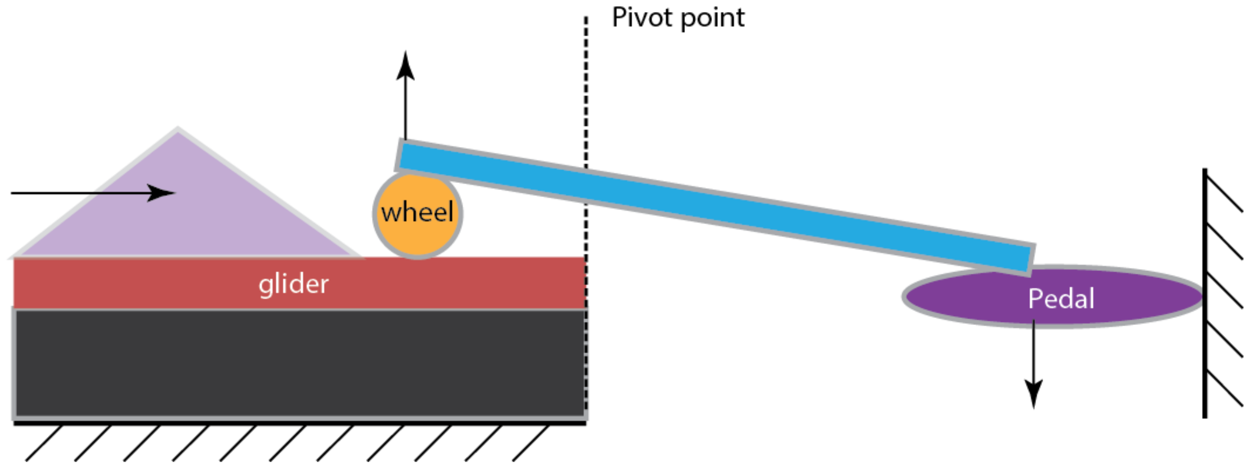


**Figure 5:** Wedge and Lever Design Alternative.  The device consists of a gliding mechanism, a wheel, and a lever with rotation about a pivot point (shown above).

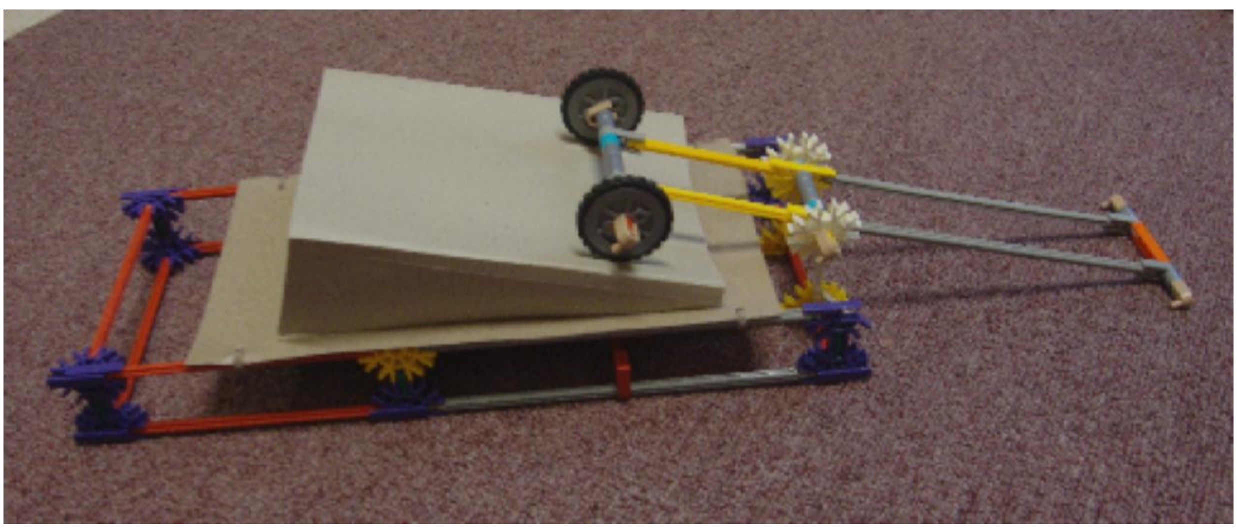

**Figure 6:** Wedge and Lever Design rough model of prototype.

*Free Weight and Pulley System*

The free weight and pulley design utilizes anterior and posterior motion in the sagittal plane to activate the pedal. This device incorporates a soft weight to depress the pedal. A fibrous cable is connected to the weight and then wraps around the user's leg. Mounted pulleys are used to guide the cable, change the direction of motion, and reduce the amount of force required to raise the weight. Figure 7 illustrates the layout and function of the device.

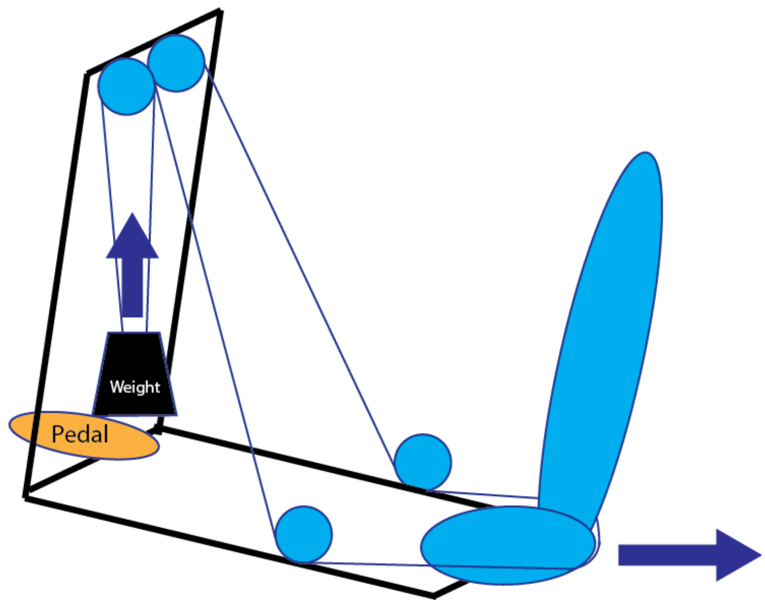


**Figure 7:** Free Weight and Pulley System. The device consists of a soft weight and multiple pulleys as well as a strap wrapped around the heel of the user. Posterior movement will raise the weight and release the pedal which deactivates the sustain function.

*Translating System*

The third design alternative is a mechanical system of levers and a wheel that will change the force's line of action from lateral to rotational and ultimately vertical. Shown in Figure 8, the red lever pivots at the connected bar when the user applies lateral pressure with the thigh. This motion will create a horizontal force onto the long gray lever, moving it left along its axis. This pushes the small attachment on the wheel, turning the wheel and causing downward movement of the attachment on the opposite side that is used to activate the pedal. The system will return to an unloaded position due to a torsional spring attached to the pivoting lever when the user ceases lateral pressure application.

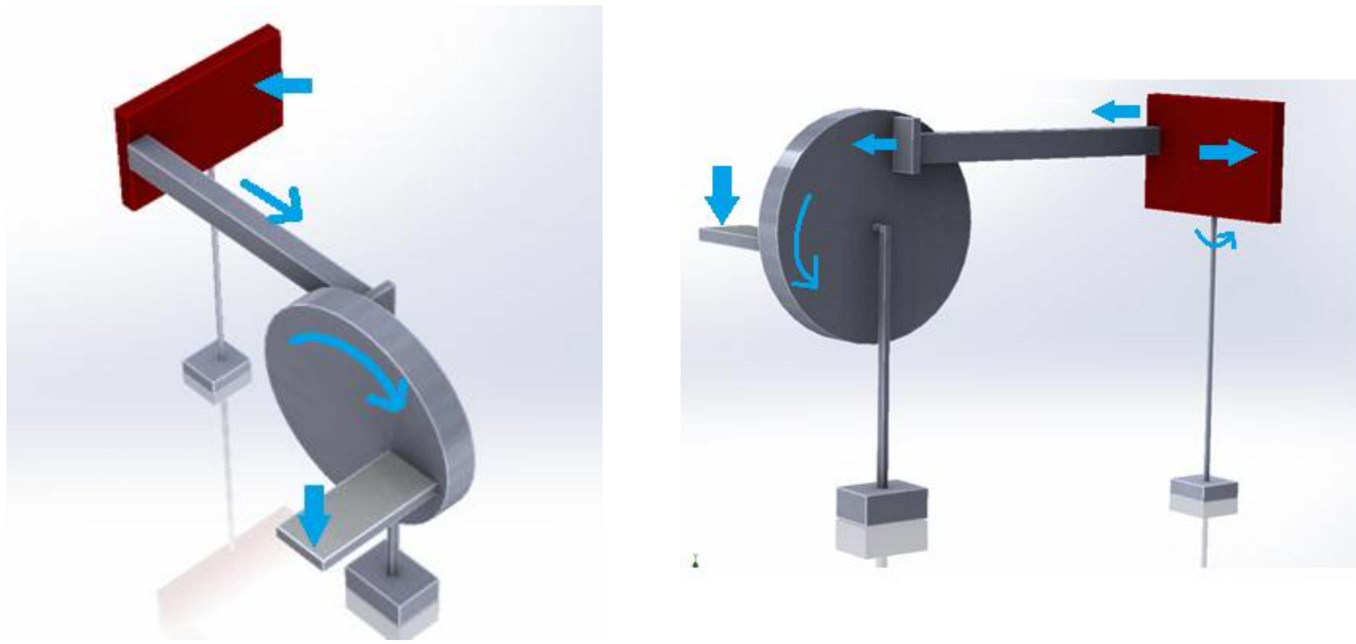

**Figure 8:** Translating System. The device consists of multiple levers, a wheel, and a spring-loaded (red) lever.

## Design Matrix

Each preliminary design has its own strengths and weaknesses. To effectively evaluate the individual points of all three designs, a design matrix was constructed and used to analyze each design alternative.

The three piano adaptation devices were rated on a variety of design criteria. These aspects included effectiveness, patient comfort, portability, cost, safety, and durability. It was determined that effectiveness and patient comfort were the most significant criteria, and were therefore awarded the greatest weights of 30 and 20 points respectively. Each design alternative was awarded a score for each category. These scores were added up to give a total score out of 100, as shown in Table 1. Based on the point distribution, the wedge and lever system received the largest allotment of points and is therefore the design we have chosen to pursue.

| Criteria | Weight | Wedge | Free Weight | Translating System |
|---|---|---|---|---|
| Effectiveness | 30 | 26 | 28 | 25 |
| Patient Comfort | 20 | 19 | 14 | 18 |
| Portability | 15 | 13 | 5 | 11 |
| Cost | 15 | 8 | 7 | 8 |
| Safety | 10 | 8 | 5 | 7 |
| Durability | 10 | 8 | 6 | 5 |
| Total | 100 | **82** | 65 | 74 |

**Table 1: Design Matrix**

The maximum point values are indicated in the second column from the left, labeled "Weight". The point allotment will be discussed in the following sections.

## Design Matrix Criteria

### *Effectiveness*

The category of effectiveness, or how well the device performs the desired task of applying different levels of force, is the most important category as the device needs to function properly. While all three designs work fairly well in accomplishing the task at hand, the free weight design was deemed the most effective with a score of 28 out of 30. With the direct application of force via the weight, this device will not lose as much energy as the other two designs. The wedge and lever device was slightly less effective with 26 out of 30, as it loses energy in the form of friction when the wedge glides back and forth. Finally, the translating system also had a slight deficit on its effectiveness with 25 out of 30 due to the many components that the force must travel through to apply a downward force, losing energy throughout.

*Patient Comfort*

Patient comfort is an important factor to consider while constructing the device, and was thus given a weight of 20 points in the design matrix. The wedge design was given the highest point score of 19 since the forward-backward motion required is easy for the user to achieve. The free weight design received a lower score of 14 points since the design would be more tiring for the user. Finally, the translating system scored just below the wedge and lever system with 18 out of 20 because while the lateral motion is easy for the client, it is not as easy as the gliding motion.

*Portability*

Portability is also an important factor, and receives a value of 15 points in the design matrix. The device will be used in multiple locations, and it should therefore be simple and easy for the user to handle. The wedge system scored the highest, receiving 13 points due to its compactness and light weight design. The translating system receives a lower score than the wedge system due to its many components and the more complicated set up. The free weight system scored the lowest, receiving 5 points out of 15 which can be attributed to its lack of rigidity and its weight.

*Safety*

The safety component had a weight of 10 points in the design matrix as there are relatively few safety risks while using this device. The wedge and the translating system scored 8 and 7 points respectively both scoring better than the free-weight system. The wedge system scored the highest since the simple design lacked dangerous components. The free-weight system scored the point value due to concerns due to the lack of portability and safety concerns while moving the device.

*Durability*

Durability is of lesser important components having a value of 10 points. The optimal lifespan of this device is estimated at five years based on overall cost and expected wear-and-tear. The free weight system and translating system both received low scores of 6 and 5 respectively. The free weight system was determined to have parts that need replacement often such as the cable and soft weight. The translating system also scored low due to the greater potential for mechanical failure of the multiple moving parts. In contrast, the wedge system scored 8 out of 10 points since it has a simple design with components less likely to need replacement.

## Future Work

### *Testing*

After fabrication, the device will require preliminary testing to ensure that it performs effectively. Pre-testing examination will include SolidWorks modeling as well as force and pressure dispersion analysis. In a physical assessment, the device will be activated approximately 20 times a minute, for a duration of 5 minutes. Quantitative evaluations will be made on the amount of force the leg will need to generate to operate the pedal and qualitative notes will be taken on the ease of the motion, how comfortable the device is to use, and how well it withstands the repetitive force applications. Finally, the device will be mailed to our client to test and comment on any modifications needed.

### *Projected cost*

We have a defined budget of $100-$200 to produce the final device. We will strive to stay within the lower limit of our budget range. The bulk of our expected expenses will be due to the mechanical parts required by the wedge design requires. A quick perusal of the McMaster-Carr catalog provides a cost estimate of $20.00 for drawer slides, about $40.00 for wheels and about $15.00 for aluminum rods [9]. Additional materials may also be needed, but their cost has not yet been determined.

*Timeline*

The following table shows our timeline with goals outlined from this semester. As you can see, filled boxes are our projected timeline and the checks are the actual progression. So far this semester, our team has stayed on track.

| **Tasks** | **September** | | | | **October** | | | | **November** | | | | | **Dec** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7 | 14 | 21 | 28 | 5 | 12 | 19 | 26 | 2 | 9 | 16 | 23 | 30 | 7 |
| **Meetings** | | | | | | | | | | | | | | |
| Advisor | **X** | **X** | **X** | **X** | **X** | | | | | | | | | |
| Client | | **X** | | | | | | | | | | | | |
| Team | **X** | **X** | **X** | **X** | **X** | **X** | **X** | | | | | | | |
| **Product Development** | | | | | | | | | | | | | | |
| Research | **X** | **X** | **X** | **X** | | | | | | | | | | |
| Brainstorming | | **X** | **X** | **X** | **X** | **X** | | | | | | | | |
| Design Matrix | | | | **X** | **X** | **X** | **X** | | | | | | | |
| Design Prototype | | | | | | **X** | **X** | | | | | | | |
| Order Materials | | | | | | | | | | | | | | |
| Fabricate Prototype | | | | | | | | | | | | | | |
| Testing | | | | | | | | | | | | | | |
| **Deliverables** | | | | | | | | | | | | | | |
| Progress Reports | **X** | **X** | **X** | **X** | **X** | **X** | **X** | | | | | | | |
| PDS | | | **X** | | | | | | | | | | | |
| Mid-Semester PPT | | | | | | | **X** | | | | | | | |
| Mid-Semester Report | | | | | | | **X** | | | | | | | |
| Final Report | | | | | | | | | | | | | | |
| Final Poster | | | | | | | | | | | | | | |
| **Website Updates** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | | | | | | | |

## References


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## Appendix

**Adaptive technology to play the piano (piano adaptation)**

**Product Design Specifications**
09/21/2012

**Group Members:** Taylor Lamberty, Myranda Schmitt, Jolene Enge, Ugeun Choi

**Advisor:** Dr. Willis Tompkins

**Function:** Mary loves to play the piano and the organ at her local church and in her community; however, Mary suffers from rheumatoid arthritis (RA). RA is a long-term disease that leads to inflammation of the joints and surrounding tissues. With the amputation of her right foot, a knee replacement, and a fused left ankle, there is a significant barrier for her to operate the three pedals on the piano. This device will apply a necessary force (8-12 lbs) to the piano pedal mechanically to enable Mary to play the piano despite the effects of rheumatoid arthritis.

**Client Requirements:**

- A device to enable piano playing without flexion in the ankle
- Easily set up and removed, portable
- Must be compatible with client's prosthetic leg
- Compatible with multiple piano models

**1. Physical and Operational Characteristics**

A. **Performance Requirements:** The device must be able to withstand repetitive use with the ability to provide varying degrees of force. It will likely be used continuously for five-minute increments, multiple times over the span of an hour. It must be operable with a minimum amount of 8 lbs of force applied.

B. **Safety:** The device should not have any sharp edges or constricting pieces since it will be utilized on the client directly. It must be able to withstand excess force to avoid failure and damaging the client's prosthetic leg.

C. **Accuracy and Reliability:** The client should be able to control the amount of force applied to the pedal over a force gradient of 8 to 12 pounds (3.6 to 5.4 kg). The device should apply a consistent level of force each time it is activated.

D. **Life in Service:** The product should maintain function for at least 5 years.

E. **Shelf life:** Since the device is to be portable, it may be stored in a vehicle and be exposed to varying temperature extremes.

F. **Operating Environment:** Primary use of the device will be indoors with room temperate of 20-25 C. It will be transported to multiple locations and therefore will be exposed to a wide range of temperature and humidity. It will be placed on the floor and may be exposed to dirty surfaces.

G. **Ergonomics:** The device will interface with a prosthetic leg and should be positioned to allow the client to sit comfortably with minimal leg movement.

H. **Size:** The product must be portable as it will be used in multiple locations. The size will also be limited by the amount of space available underneath the piano, between the pedals, and between the piano and the user.

I. **Weight:** The device should be light weight so that it is portable because the client will need to move it independently. Ideally, the device will weigh no more than 15 lbs.

J. **Materials:** The device should be constructed so that it is durable, but not heavy. It should also be made with materials that are not harmful to the client since some parts of it will have direct contact with the prostheses and/or clothing.

K. **Aesthetics, Appearance and Finish:** The finished product should be aesthetically pleasing given that it will be utilized in public. It should also be as inconspicuous as possible.

**2. Production Characteristics**

A. **Quantity:** We will be constructing one device.

B. **Target Product cost:** The target product cost will be between $100 and $200.

**3. Miscellaneous**

A. **Standards and Specifications:** The device should comply with applicable ADA regulations.

B. **Competition:** There are two known current devices for consumers with limited mobility in the lower body. One uses lateral movement of the leg to press the pedal, and the other uses a wireless device to sense the movement of the mouth which in turn, applied force to the pedal.