WORCESTER POLYTECHNIC INSTITUTE

Worcester Earn-A-Bike

Creating An Adaptive Bicycle

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Abstract

The goal of this project was to create an adaptive bicycle design for the community non-profit organization, Worcester Earn-A-Bike, so that they can provide bicycles to teenagers with Down syndrome, autism spectrum disorder, and cerebral palsy. Through interviews with adaptive cycling organizations and families of people with disabilities, we discovered that adaptive bicycles are not widely available, tend to be very expensive, and are only suited to a specific individual's needs. Our group developed several potential adaptive bicycle designs which we then analyzed in terms of build cost, fabrication time, and benefits provided for those with our targeted disabilities. In the end, we designed and prototyped a slim tricycle because that design solves most of the issues that those with our selected disabilities have and can be made by modifying a standard adult bicycle with parts available at Earn-A-Bike's shop.

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Professor Corey Dehner
Director, Worcester Community Project Center

Professor Stephen McCauley
Co-Advisor, Worcester Community Project Center

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The Cotting School

Physical therapists for showing us their adaptive bicycle fleet

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For their support and contributions to our project

All Members and Friends of the Earn-A-Bike Community

Who took the time to speak with us throughout the course of our project!

Executive Summary

Wind in your hair, freedom at your reach and the world at your fingertips: all you need to do is pedal. Everyone loves the exhilarating feeling of riding a bike, but for some this feat is unattainable. For many people, bicycle riding presents a variety of experiences that they can enjoy with family and friends. Unfortunately, people with physical or cognitive disabilities may struggle with balance, coordination, and physical strength, which can inhibit their ability to ride a traditional bicycle. Accommodating various disabilities often involves extensive modifications to a traditional bicycle's design.

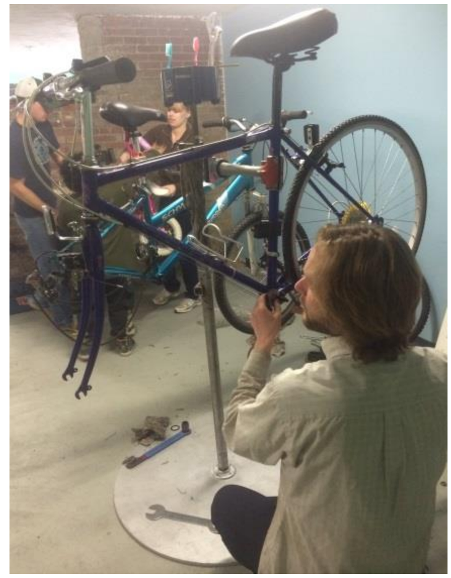


Figure 1: Volunteers at Earn-A-Bike perform a variety of tasks, from bicycle servicing to shop maintenance.

Worcester Earn-A-Bike (EAB) is a community non-profit organization which supplies bicycles to individuals who volunteer in the shop once a certain number of volunteer hours are accrued. Earn-A-Bike aims to:

> "Teach fun, affordable bike repair to neighborhood youth and community members by providing tools, instruction, and repairable bikes and parts. Earn-A-Bike encourages bicycle riding as an empowering, economical, and healthy alternative to car culture (About, n.d.)."

Worcester Earn-A-Bike strives to provide bicycles to everyone in the community including individuals who require adaptive bicycles. After receiving inquiries about available adaptive bicycles for people with different disabilities, Earn-A-Bike challenged our Interactive Qualifying Project (IQP) team to design and prototype an adaptive bicycle for individuals with Down syndrome, autism spectrum disorder (ASD), and cerebral palsy.

I. Disabilities Create a Challenge for Bicycle Riding

Bicycles are a great way to be active while enjoying the outdoors and are one of the most popular forms of exercise, recreation, and transportation throughout the world. While riding a bicycle may seem a simple task for the majority of the population, it can be a challenge for adults and children with cognitive and physical disabilities.

For those diagnosed with Down syndrome, autism spectrum disorder, and cerebral palsy, balancing, steering, and pedaling may be particularly difficult obstacles to overcome (Mathias, 2011). When focusing on Down syndrome, autism spectrum disorder, and cerebral palsy, there are unique difficulties associated with bicycling that become apparent. People with Down syndrome may have delayed motor skills and a difference in movement patterns (Ulrich, Burghardt, Lloyd, Tiernan, Hornyak, 2011). Similarly, cerebral palsy affects the development of coordination and posture limiting the activities in which individuals can participate. Symptoms include muscle tone abnormalities, impairment of balance and coordination, decreased strength, and loss of selective motor control (Papavasilou, 2009). Through research and interviewing members of the adaptive bicycle community, including a Special Olympics cycling coach, physical therapists at special education schools, and adaptive bicycle manufacturers, we discovered balancing was the greatest limitation associated with these three disabilities.

Figure 2: Example of an adaptive tricycle used by physical therapists at the Cotting School.

Although it may be difficult for people with disabilities to ride a bicycle, there are many associated social and physical benefits. Riding a bicycle may improve a person's self-perception and confidence in social situations. Cycling with family members and friends can help facilitate communication and bonding. Also, cycling is a great form of exercise which helps fight obesity and health concerns. Bicycles can also provide increased mobility as they offer a form of transportation. Lastly, cycling can be a form of physical therapy or rehabilitation, as it can help improve balance and fitness abilities. The numerous benefits to cycling motivate Worcester Earn-A-Bike to provide everyone the opportunity to ride and experience the thrill of bicycling.

II. Considerations and Project Goal

Cost, availability, and design style are the primary obstacles people with physical and cognitive disabilities face when trying to purchase an adaptive bicycle. Since adaptive bicycles require additional specialized features beyond traditional bicycles, the prices are significantly higher. This large gap in prices between adaptive and traditional bicycles is just one reason alternative bicycles are inaccessible to most people. Availability is another issue with adaptive bicycles since the percentage of people with disabilities who are able to ride and purchase these bicycles is small; only a few specialized companies produce and sell adaptive bicycles. Lastly, many adaptive bicycles have been extensively modified, making them stand out in a crowd, which can be embarrassing to the rider (Lewak, Doree, 2011).

Since cost, availability, and embarrassment make it difficult for people with disabilities to find a bicycle that satisfies their needs, the goal of our project was to design a bicycle that could be fabricated right in Earn-A-Bike's shop using donated parts to limit the cost. The bicycle we designed had to be safe, comfortable, user-friendly, affordable, and upgradeable so that it may be used by patrons of our sponsor, Worcester Earn-A-Bike. In order to achieve our goal, we developed the following objectives:

1. Identify appropriate modifications that can be made to existing bicycles to accommodate people with Down syndrome, autism, and cerebral palsy.

2. Create bicycle designs which incorporate the modifications identified in Objective 1.

3. Assess the feasibility of the proposed designs in terms of cost, materials, and fabrication.

4. Prototype the most feasible design

5. Identify potential sources of funding for Earn-A-Bike.

6. Determine how to educate the Earn-A-Bike community on adaptive bicycles.

Earn-A-Bike is a community organization, with most of their volunteers living in surrounding neighborhoods or nearby towns. Therefore, the bicycle we designed would be primarily used for members of the Earn-A-Bike community who desire to ride adaptive bicycles.

III. Creating an Adaptive Bicycle

Our goal was to design a bicycle which is accessible to adults with Down syndrome, autism spectrum disorder, and cerebral palsy. We first had to identify appropriate modifications that could be made to existing bicycles to accommodate the targeted disabilities. We completed this task through research and interviews with members of different cycling communities and organizations, including Special Olympics, Bicycle Man, AmTryke, My Team Triumph, Boston College Campus School, and the Cotting School. We chose these organizations because of their active involvement in providing or working with adaptive bicycles for people with disabilities.

Figure 3: Conceptualizing the design prototype, which uses readily available bicycle parts from Earn-A-Bike.

We also conducted interviews with families recommended by our sponsors who had personal experiences using adaptive bicycles.

Some People with Disabilities Have a Fear of Bicycle Riding.

One common theme we found among riders with disabilities and their families that we interviewed was the fear of riding a bicycle induced by a traumatic event. In some instances, the rider had fallen off of a bicycle and consequently lost interest in the activity due to the fear of falling again.

Modifying Certain Components of a Bicycle can Make the Bicycle more User-Friendly for People with Cognitive Disabilities.

Aside from social and psychological considerations for riders with disabilities, we also found that traditional bicycle height, gearing, and braking systems inhibited riding by people with disabilities.

From our interviews, we found that lower seating is preferred so riders can firmly plant their feet on the ground when seated. Limiting the number of gears is beneficial to people with cognitive disabilities, making it simpler for them to select the proper gear for a given situation. Our design limits the amount of gears by only having one gear on the axle and using the existing gears on the front crank of the bicycle. Additionally, our team found that hand brakes are the most effective for people with disabilities. The other types of brakes commonly used on bicycles are coaster brakes, which engage when the rider pedals in reverse. Since our target population has cognitive disabilities, our interviews revealed that the concept of pedaling backwards to stop can be difficult to grasp.

Next we created multiple bicycle designs which incorporated the modifications identified through our interviews and assessed the feasibility of each design. These designs included using gyroscopic wheels, a crank forward bicycle frame, an A-frame attachment, or a slim tricycle design. We assessed the feasibility of building these four designs based on the resources available at Earn-A-Bike and the costs associated with building and modifying them.

A Slim Tricycle Utilizing Available Parts from Earn-A-Bike was the most Feasible Design.

Based on our assessments, we determined that the slim tricycle design consisting of a removable rear axle which can be mounted to any traditional bicycle frame is the best approach to creating an adaptive bicycle given the low cost, material availability, and minimal fabrication.

The slim tricycle design includes modifying a standard two-wheeled bicycle by removing the rear wheel and adding an axle that can be bolted onto the rear dropouts. Considering the aesthetics of the design, the axle was fabricated to be shorter than most standard tricycle designs. Also, the rear wheels attached to the axle were standard 26" bicycle wheels. This made the design look similar to a standard bicycle when viewed from the side, limiting the degree to which the bicycle stands out in a crowd and embarrassment of the rider.

Figure 4: Our IQP team with our finished prototype.

IV. Recommendations & Conclusions

As part of our project deliverables, we will be leaving Earn-A-Bike with our prototype bicycle for use at the shop. Below we discuss our recommendations for the continuing development of adaptive bicycles at Earn-A-Bike.

Continue Testing the Adaptive Bicycle Prototype for Safety.

We recommend that the design be further tested to ensure it is safe to ride. This prototype should also serve as a base upon which other modifications could be affixed or developed. We believe our bicycle design will be a great resource for the shop to get people with disabilities interested in cycling.

Apply to Grants which Provide Funding for Adaptive Bicycle Projects.

Additionally, part of our project involved researching potential sources of funding for our bicycle and future projects at Earn-A-Bike. In collaboration with our sponsors, we determined grants would serve as the most viable source of funding for Earn-A-Bike, both because of the variety of grants available and the limitations of crowdfunding. We created a spreadsheet listing grants that focus on non-profit organizations or adaptive bicycles as a resource for EAB to use. The complete list of grants and organizations which we recommend are included in Appendix E.

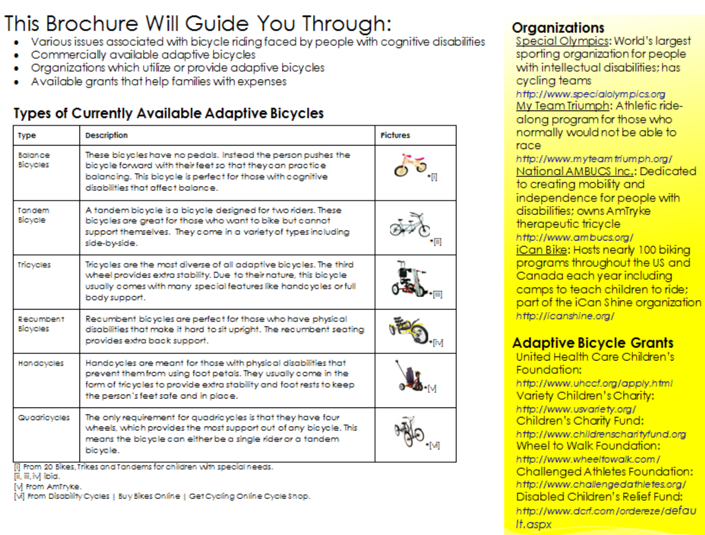
Specifically, we recommend that Earn-A-Bike consider applying to the Fletcher Foundation, Stoddard Charitable Trust, and Wyman-Gordon Foundation. These grants primarily provide funding for Worcester based non-profit organizations which make significant impacts in the Worcester community. We believe that Earn-A-Bike's mission to provide adaptive bicycle for people with disabilities and other community members meets the criteria, and recommend they pursue application to these foundations.

There are also foundations nation-wide which provide funding specifically for bicycle programs and projects. We recommend Earn-A-Bike consider applying to the 7 Hills Foundation, People For Bikes, and the League of American Bicyclists. For example, the League of American Bicyclists provides funding specifically for women-oriented cycling programs, a niche in the Worcester community which Earn-A-Bike fills by offering weekly Women and Trans shop nights.

Distribute the Informational Brochures to Educate Community Members on Available Adaptive Bicycles and Programs.

Our group also created an informational brochure on adaptive bicycles which includes a number of resources for families. These resources include organizations which develop adaptive bicycles, organizations which sponsor athletic events, and various foundations which provide grants specifically for families in need of an adaptive bicycle. We also included a chart of adaptive bicycles currently on the market for a range of different disabilities, with a description of our bicycle design to serve as an example of what Earn-A-Bike could provide to the community. We recommend Earn-A-Bike distributes these brochures to inform community families on adaptive bicycles and what resources are available. Full screen views of the brochure are included in Appendix E.

Figure 6: Front panels of the brochure, which show our bicycle as well as the Earn-A-Bike shop hours and available



This Brochure Will Guide You Through:

- Various issues associated with bicycle riding faced by people with cognitive disabilities
- Commercially available adaptive bicycles
- Organizations which utilize or provide adaptive bicycles
- Available grants that help families with expenses

Types of Currently Available Adaptive Bicycles

Type	Description	Pictures
Balance Bicycles	These bicycles have no pedals. Instead the person pushes the bicycle forward with their feet so that they can practice balancing. This bicycle is perfect for those with cognitive disabilities that affect balance.	[i]
Tandem Bicycle	A tandem bicycle is a bicycle designed for two riders. These bicycles are great for those who want to bike but cannot support themselves. They come in a variety of types including side-by-side.	[ii]
Tricycles	Tricycles are the most diverse of all adaptive bicycles. The third wheel provides extra stability. Due to their nature, this bicycle usually comes with many special features like handcycles or full body support.	[iii]
Recumbent Bicycles	Recumbent bicycles are perfect for those who have physical disabilities that make it hard to sit upright. The recumbent seating provides extra back support.	[iv]
Handcycles	Handcycles are meant for those with physical disabilities that prevent them from using foot petals. They usually come in the form of tricycles to provide extra stability and foot rests to keep the person's feet safe and in place.	[v]
Quadricycles	The only requirement for quadricycles is that they have four wheels, which provides the most support out of any bicycle. This means the bicycle can either be a single rider or a tandem bicycle.	[vi]

[i] From 20 Bikes, Trikes and Tandems for children with special needs.
[ii, iii, iv] ibid.
[v] From AmTryke.
[vi] From Disability Cycles | Buy Bikes Online | Get Cycling Online Cycle Shop.

Organizations

Special Olympics: World's largest sporting organization for people with intellectual disabilities; has cycling teams
http://www.specialolympics.org
My Team Triumph: Athletic ride-along program for those who normally would not be able to race
http://www.myteamtriumph.org/
National AMBUCS Inc.: Dedicated to creating mobility and independence for people with disabilities; owns AmTryke therapeutic tricycle
http://www.ambucs.org/
iCan Bike: Hosts nearly 100 biking programs throughout the US and Canada each year including camps to teach children to ride; part of the iCan Shine organization
http://icanshine.org/

Adaptive Bicycle Grants

United Health Care Children's Foundation:
http://www.uhccf.org/apply.html
Variety Children's Charity:
http://www.usvariety.org/
Children's Charity Fund:
http://www.childrenscharityfund.org
Wheel to Walk Foundation:
http://www.wheeltowalk.com/
Challenged Athletes Foundation:
http://www.challengedathletes.org/
Disabled Children's Relief Fund:
http://www.dcrf.com/ordereze/default.aspx

Figure 5: Inside panels of the brochure, which includes available adaptive bicycles, cycling programs, and grants families can apply to.

Our group believes that our project successfully provided Worcester Earn-A-Bike the ability to expand their organization to provide bicycles for people with disabilities, meeting their overall goal of providing bicycles for everyone in the Worcester community.

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Bicycle Dynamics	Bror Axelsson	Edited by All
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Relevant Organizations & Resources	Aida Waller	Edited by All
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Chapter 1: Introduction

Wind in your hair, freedom at your reach and the world at your fingertips: all you need to do is pedal. Everyone loves the exhilarating feeling of riding a bike, but for some this feat is unattainable. For many people, bicycle riding presents a variety of experiences that they can enjoy with family and friends. Unfortunately, people with physical or cognitive disabilities may struggle with balance, coordination, and physical strength, which can inhibit their ability to ride a traditional bicycle. Accommodating various disabilities often involves extensive modifications to a traditional bicycle's design.

Worcester Earn-A-Bike, the non-profit organization which sponsored this project, provides people in Worcester, Massachusetts with a safe place for learning unique skills, such as how to repair and maintain bicycles. People who participate also learn the importance of community involvement through volunteering and shop events. At Earn-A-Bike, community members may volunteer their time fixing damaged bicycles and maintaining the Earn-A-Bike shop, eventually earning the right to build their own bicycle. Earn-A-Bike's desire to provide bicycles to all members of the Worcester community motivated them to develop adaptive bicycles for community members with special needs. The shop managers at Earn-A-Bike learned of the need for adaptive bicycles after hearing a community member was embarrassed to ride an adaptive bicycle among peers because of how different the bicycle looked. Unable to provide a solution, our sponsors began this collaborative project between Worcester Polytechnic Institute and Earn-A-Bike to research different designs for alternative bicycles which suited the needs of people with Down syndrome, autism, and cerebral palsy.

While there are adaptive bicycles commercially available for people with disabilities, these bicycles are typically very costly. Consequently, these bicycles are often inaccessible to the individuals who need them and to organizations who desire to provide them. Since Earn-A-Bike is a non-profit organization, we developed a bicycle design which can be affordably constructed and easily maintained using materials readily available from donated bicycles. By designing such a bicycle, we filled a gap in the adaptive bicycle market from which the patrons and volunteers of Earn-A-Bike can benefit. The challenges associated with designing an adaptive bicycle are numerous, and include making the bicycle accessible to a wide range of disabilities and safe for anyone to use.

In the second chapter of this proposal, our literature review, we provide background information about our project and the need it filled in the Worcester community. We begin by discussing the various disabilities that affect bicycle riding in order to give some context on the need for adaptive bicycles. We then explore the different adaptive bicycles available, the special features of adaptive bicycles, and describe various companies and organizations that work with adaptive bicycles. Finally, we introduce some of the specifics of our project and our sponsor, Worcester Earn-A-Bike.

In the third chapter, our project methodology, we discuss our approach to accomplishing our goal of designing an adaptive bicycle for adults with Down syndrome, autism, and cerebral palsy.

Our fourth chapter explains our project findings, and includes the information we gathered from the various individuals and organizations that we contacted. We explain how we used their recommendations to develop different bicycle designs, and how we decided which design to manufacture and prototype. Additionally, we discuss various sources of funding for future Earn-A-Bike projects, including Worcester-based charitable foundations and crowdfunding.

In the final chapter of this report we offer our recommendations. In this chapter we discuss the bicycle design which would be most beneficial to Earn-A-Bike, as well as the most beneficial sources of funding for future projects. We also describe the various resources we have developed for the Earn-A-Bike community, including an informational brochure.

Through our efforts, we succeeded in designing and building an affordable, safe adaptive bicycle for members of the Worcester Earn-A-Bike community with cognitive disabilities.

Chapter 2: Literature Review

I. Introduction

Bicycles are a great way to be active while enjoying the outdoors and are one of the most popular forms of exercise, recreation, and transportation throughout the world. Biking serves as a social activity which can be enjoyed with family members and peers. Energy efficient and a great form of transportation, bicycling is also environmentally-friendly. What may seem a simple task for the majority of the population can be a challenge for adults and children with cognitive and physical disabilities. For those diagnosed with intellectual and developmental disabilities, balancing, steering, and pedaling may be particularly difficult obstacles to overcome (Mathias, 2011). Based on a person's disability and the needs and comforts of the rider, alternative bicycles can be adapted to accommodate a variety of individuals.

In this chapter, we begin by discussing the disabilities that affect bicycle riding in order to give perspective on the need for adaptive bicycles. In section II, we explore the physical and social aspects of riding a bicycle for those with disabilities and in section III we discuss the importance of riding a bicycle for people with disabilities. Next we analyze the different adaptive bicycles commercially available and which disabilities they most benefit in section IV. Following this is a brief explanation of the dynamics of bicycles and some adaptations which can be made to bicycles to improve balance in section V. In section VI we discuss some of the issues with current adaptive bicycles available on the market. Section VII includes descriptions of organizations that are involved with adaptive bicycles and bicycle races for the handicapped. In section VIII we describe the specifics of our project and our sponsor, Worcester Earn-A-Bike. Finally, in section IX, we provide information different fundraising options Earn-A-Bike could utilize for future projects.

II. Disabilities Create a Challenge for Bicycle Riding

a. Developmental Disabilities

A mental illness can be described as a medical condition that affects a person's thinking, feeling, mood, and ability to relate to others and perform daily functions (Mental Illness, n.d.). Down syndrome and autism spectrum disorder (ASD) are common genetic disorders that affect one's ability to learn to ride a bicycle.

Down syndrome is a genetic disease resulting from an extra twenty-first chromosome, and is the most common genetic cause of an intellectual disability (MacDonald, Esposito, Hauck, Jeong, Hornyak, Argento, Ulrich, 2012). Those with Down syndrome learn motor skills much later than most children and display differences in their movement patterns (Ulrich, Burghardt, Lloyd, Tiernan, Hornyak, 2011).

In the United States, two-wheeled bicycle riding skills are considered a societal norm for most children by the time they reach six to seven years of age (MacDonald, Jaszewski, Esposito, Ulrich, 2011). However, a study published in 2011 showed that less than ten percent of children with Down syndrome whom are eight to fifteen years old could ride a two wheeled bicycle (Ulrich, Burghardt, Lloyd, Tiernan, & Hornyak, 2011). It may be harder for those with Down syndrome to ride a bicycle since they acquire different motor skills at a later age than most children. This difference in motor skills development also makes it more difficult for them to balance on a standard two-wheeled bicycle.

Autism spectrum disorder is a developmental disorder resulting in lack of social skills, communication, and repetitive or restricted interests (American Psychiatric Association, 1994; MacDonald, Jaszewski, Esposito, Ulrich, 2011). The wider the social gap between children with ASD and their peers, the quicker they can be rejected (MacDonald, Jaszewski, Esposito, Ulrich, 2011). Many children with ASD prefer individual activities without performance expectations that may influence a team's outcome (MacDonald, Esposito, Hauck, Jeong, Hornyak, Argento, Ulrich, 2012). Therefore, riding a bicycle could be a great form of exercise and recreation for these kids, as opposed to team sports such as soccer or basketball. Children with ASD tend to keep to themselves since it is harder for them to connect with their peers. Riding a bicycle could help them socialize and connect with their peers. However, children with ASD may also have issues with balance and could consequently struggle to ride a standard bicycle.

b. Physical Disabilities

Physical disabilities can also affect one's ability to ride a bicycle. These disabilities can range from cerebral palsy (CP) and muscular dystrophy (MD), which affect muscle tone, to amputation, which is the loss of a limb. There is a broad range of physical disabilities which all have different characteristics affecting one's ability to ride a standard bicycle.

Cerebral palsy is a disorder that affects the development of movement and posture causing activity limitation (Papavasiliou, 2009). Other symptoms of the disorder include muscle tone abnormalities, impairment of balance and coordination, decreased strength, and loss of selective motor control (Papavasiliou, 2009). Muscular dystrophy weakens the muscles in the body due to the fact that those with the disorder have missing or incorrect information in their genes, preventing them from making proteins to keep their muscles healthy (Clark, 2010). Muscular dystrophy weakens the muscles over time, so as a person ages they slowly lose the ability to do tasks or activities they could do when younger. Depending on the type and severity of MD, people can have joint problems or develop scoliosis. Some with the disease may even require a wheelchair. It can be challenging for people with these disabilities to ride a bicycle since they might not have the muscle strength to pedal for extended periods of time.

Although there are several genetic physical disabilities, many physical disabilities can result from accidents or traumatic experiences, such as people with amputated limbs. Those with amputated limbs can range from war veterans to victims of accidents or illness. Traditional bicycles are not always an option for those who have had a limb removed. However, depending on the limb and the number of limbs missing, alternative bicycles may be an option. For example, if someone is missing a leg, there are bicycles that have hand pedals for movement. One of the more popular forms of exercise for individuals with amputated limbs is bicycling, as it is easy on the ankle and knee joints, increases muscle strength, and the aerobic activity is good for the heart (Hibbet, n.d.). Bicycling helps people with amputated limbs develop balance and coordination skills and helps increase range of motion in the hips and knees (ibid).

There are many disabilities that prevent or pose a challenge to riding a bicycle. The cognitive and physical disabilities listed are just some of the most relevant and common ones; however, there are various types of conditions which may affect a person's ability to ride a two-wheeled bicycle. Table 1 outlines various disabilities and how they affect one's ability to ride a bicycle. While bicycling may be difficult for those with cognitive and physical handicaps, there are many social and physical reasons that those with disabilities should learn to ride a bicycle. We elaborate on these benefits of bicycle riding in the next section.

Table 1: How Various Disabilities Impede Bicycle Riding

Disability	Factors Affecting Bicycle Riding
Down syndrome	· Delayed motor skills and difference in movement patterns [1]
Autism spectrum disorder	· Difficulty understanding communication and focusing · Balance issues [2]
Fetal alcohol syndrome	· Learning, thinking, memory problems · Cognitive, behavioral, growth problems [3]
Traumatic brain injury	· Memory, concentration, attention, thinking problems · Weakness/ numbness in extremities and loss of coordination [4]
Cerebral palsy	· Muscle tone abnormalities & decreased strength · Impairment of balance and coordination · Loss of selective motor control [5]
Muscular dystrophy	· Muscle weakness · Joint problems & scoliosis [6]
Multiple sclerosis	· Muscle weakness · Balance and movement problems [7]
Spina bifida	· Muscle weakness · Balance, movement, and coordination problems [8]
Rheumatoid arthritis	· Joint problems in hands, feet, wrists, elbows, knees, and ankles [9]
Osteoarthritis	· Stiffness of the lower back, hips, knees, feet, neck, and fingers [10]
Fibromyalgia	· Pain & fatigue · Memory problems · Mood changes [11]
Amputation	· Missing limbs [12]

[1] Ulrich, Burghardt, Lloyd, Tiernan, Hornyak, 2011.
[2] American Psychiatric Association, 1994; MacDonald, Jaszewski, Esposito, Ulrich, 2011.
[3] CareNotes, 2013.
[4] NINDS Traumatic Brain Injury Information Page, n.d.
[5] Papavasiliou, 2009.
[6] Clark, 2010.
[7] A.D.A.M Medical Encyclopedia, 2013.
[8] Spina Bifida- Topic Overview, 2011.
[9] What is Rheumatoid Arthritis?, n.d.
[10] What is Osteoarthritis?, n.d.
[11] What is Fibromyalgia?, n.d.
[12] Hibbet, n.d.

III. Importance of Bicycle Riding for those with Disabilities

Even though riding a bicycle can be difficult for those with disabilities, it fulfills a number of social and physical therapy needs and can therefore help individuals lead a healthy lifestyle. Riding a bicycle may improve a person's self-perception and confidence in social situations. It can be an activity to share with family members and friends facilitating communication and bonding. As a great form of exercise, bicycling can be used to prevent obesity and health concerns. Also, bicycling can increase the mobility of a person with a disability since it can be used for transportation. Lastly, biking can be used to improve balance and fitness abilities as a form of physical therapy or rehabilitation method.

Socially, it is harder for those with disabilities to fit in with their peers. Riding a bicycle is a societal norm, and children with disabilities may feel left out if they never learn. Being able to participate in a culture of bicycle-riding will give those with special needs or handicaps a sense of belonging. Riding a bicycle and being able to participate in bicycle-riding events boosts the self-esteem, confidence, and independence of the person with a disability (Mathias, 2011; Schleien & Mactavish, 2004). Learning to ride a bicycle gives children a sense of freedom since they are unable to perform other daily tasks in everyday life (Vanbergeijk, 2013). One family whose daughter has autism explained in a study, "Since learning to ride, Mandy's self-confidence has trickled over into many aspects of her life. She is now eager to take part in family photos, placing herself front and center, which she had never done before" (Esposito, Jaszewski, MacDonald, Ulrich, 2011). Learning to ride a bicycle may help children with other aspects of their life, just like Mandy.

Bicycle riding is an important activity because it helps families bond and improves communication. A study on the connection between family recreational outings and the social development of children with disabilities was conducted in 2004 by Schleien and Mactavish, professors at the University of North Carolina Greensboro and the University of Manitoba, respectively. Their study revealed that by giving someone the opportunity to ride a bicycle, you are enabling them to participate in social gatherings, which they could not do before (Schleien & Mactavish, 2004). For families, riding bicycles "makes us closer as a family, gives us something fun to do as a family, improves parents' communication with the children, and improves quality of life" (ibid). Riding a bicycle helps children with disabilities connect with other family members, develop skills, and set foundations for the future. One family proclaims:

> "Our son is behind in most skills, so one of the benefits to doing things as a family is he gets a chance to work on these things in a fun way and have unconditional acceptance and support along the way. I'm not sure there are many other situations in his life where that is possible…but maybe if he learns how to do some of these things now at home with us, he'll have a better chance of making friends to do things on his own with" (ibid).

It is nice for those with disabilities to be able to ride bicycles in order to bond with their families and to spend quality time together.

Unfortunately, physical inactivity and obesity are growing problems for people with intellectual disabilities since they are less active than those without intellectual and developmental disabilities (Ulrich, Burghardt, Lloyd, Tiernan, & Hornyak, 2011; MacDonald, Esposito, Hauck, Jeong, Hornyak, Argento, Ulrich, 2012). They are also at a higher risk for osteoporosis, musculoskeletal disorders, and cardiovascular health problems (MacDonald, Esposito, Hauck, Jeong, Hornyak, Argento, & Ulrich, 2012). Learning to ride a bicycle is a good way for people with disabilities to lead a healthier lifestyle and prevent obesity. In one study, those who learned to ride a bicycle demonstrated a significant decrease in time spent in sedentary activity twelve months after training and had a reduction in subcutaneous fat (Ulrich, Burghardt, Lloyd, Tiernan, & Hornyak, 2011). If able to learn how to ride a bicycle, people with disabilities could avoid obesity and associated conditions.

Learning to ride a bicycle could increase the mobility of children with a handicap, allowing them to use the bicycle as a form of transportation to go to work, do errands, or visit friends (Vanbergeijk, 2013). An article by Blue (2011) features a child, Cyndi Sutter, who survived a traumatic brain injury and had to relearn how to walk. She finally bought an upright three-wheeled bicycle two years after the incident. She stated, “When I got it, I felt more free. I could go to the library and not have to take the bus” (Blue, 2011). If they are able to ride a bicycle, people with disabilities can do errands independently without relying on others for transportation.

Bicycling also helps with balance and fitness abilities (Mathias, 2011; Schleien & Mactavish, 2004). Although people with disabilities may have trouble balancing, learning to ride a bicycle helps improve their balance and eventually these skills can be acquired. Riding a bicycle is a form of physical therapy and is used for rehabilitation if a person has been in an accident. Bicycle riding can also help with motor skill development for those born with a disability. Learning to ride a bicycle is important for everyone. Bicycles with various accommodations are available. Biking is a great form of exercise which can improve a person’s health, and foster social and developmental growth. The next section outlines how people with disabilities learn to ride a bicycle as well as different adaptive bicycles currently on the market.

IV. Adaptive Bicycles for Various Disabilities

a. Learning to Ride

Before learning to ride a two-wheeled bicycle, many children begin by riding tricycles or using training wheels. Without realizing it, at each stage the child learns more about bicycle dynamics and their limitations as a rider. None of this knowledge is intentionally grasped, instead, riding a bicycle becomes instinct, and as children grow they surpass their limitations with ease. To many, learning to ride a two-wheeled bicycle is simple: a parent pushes the bicycle as the child tries to maintain balance, and once the child gains balance the parent lets go of the bicycle. The child never has to think about how to balance; he or she does it instinctually. Children with developmental disabilities do not have the same instinctual reactions as other children, making it more difficult to learn how to balance. Those with cognitive handicaps do not grasp the concepts that many others pick up easily, like how to balance and pedal at the same time. Some children with physical handicaps require a lot of extra practice to balance, while others are physically incapable of holding themselves steady (Åström, Klein, & Lennartsson, 2005).

To successfully teach a child how to ride a bicycle, the teacher must understand bicycle dynamics, rider perceptions, and limitations (Åström, Klein, & Lennartsson, 2005). Physicists Åström, Klein, and Lennartsson, propose that by making a bicycle more stable to ride in the beginning, children with disabilities will become more confident, and eventually learn to ride a traditional bicycle. One way to make the bicycle more stable is to replace the standard bicycle wheels with nearly flat rollers (ibid). These rollers supply more stability and enable the child to practice pedaling and balancing without the fear of falling over. The roller's radius can be modified, so when the child adapts to the rollers and can maintain balance, the rollers can be replaced with wheels (ibid). These small modifications can teach children how to balance without invoking the fear of falling often experienced on a standard two-wheeled bicycle. Other methods include building up to riding standard bicycles by practicing on adaptive bicycles. In the next section of the paper, we discuss different adaptive bicycles and how they assist those who are developmentally or physically disabled.

b. Available Adaptive Bicycles

There are a variety of bicycles for people with disabilities because each disorder has different needs when it comes to bicycle-riding. In Table 2 we provide the names, descriptions, and a picture of the most common types of available adaptive bicycles.

Table 2: Types of Adaptive Bicycles

Type	Description	Pictures
Balance Bicycles	These bicycles have no pedals. Instead the person pushes the bicycle forward with their feet so that they can practice balancing. This bicycle is perfect for those with cognitive disabilities that affect balance.	 [i]
Tandem Bicycle	A tandem bicycle is a bicycle designed for two riders. These bicycles are great for those who want to bike but cannot support themselves. They come in a variety of types including side-by-side.	 [ii]
Tricycles	Tricycles are the most diverse of all adaptive bicycles. The third wheel provides extra stability. Due to their nature, this bicycle usually comes with many special features like handcycles or full body support.	 [iii]
Recumbent Bicycles	Recumbent bicycles are perfect for those who have physical disabilities that make it hard to sit upright. The recumbent seating provides extra back support.	 [iv]
Handcycles	Handcycles are meant for those with physical disabilities that prevent them from using foot petals. They usually come in the form of tricycles to provide extra stability and foot rests to keep the person's feet safe and in place.	 [v]
Quadricycles	The only requirement for quadricycles is that they have four wheels, which provides the most support out of any bicycle. This means the bicycle can either be a single rider or a tandem bicycle.	 [vi]

[i] From 20 Bikes, Trikes and Tandems for children with special needs.
[ii] ibid.
[iii] ibid.
[iv] ibid.
[v] From AmTryke.
[vi] From Disability Cycles | Buy Bikes Online | Get Cycling Online Cycle Shop.

In the following sections, we elaborate on each type of adaptive bicycle, including their prices, intended age ranges for riders, and special features meant to help with handicaps in the remainder of this section.

Balance Bicycles

The first type of alternative bicycle we will discuss is balance bicycles. Balance bicycles are useful for those with cognitive disabilities that make it hard to focus on balancing and pedaling at the same time, or for those with physical disabilities who have a hard time balancing. The kaZAM bicycle is intended for children between the ages of two and five (although there is an adult model on the market as well) and costs approximately 100 dollars. Instead of bicycling pedals, this bicycle has a balance pedal for children to rest their feet on, and the children move the bicycle by stepping on the ground as if they were walking. The balance pedal makes it easier for children with balance issues to ride a bicycle because they do not have to worry about pedaling or balancing the bicycle (20 Bikes, Trikes and Tandems for Children with Special Needs). In general, the balance bicycle is usually less expensive and more easily manufactured than other adaptive bicycles since in most cases they only require removing the pedals. The main focus of balance bicycles is to help build confidence rather than adapt to a specific physical need.

Tandem Bicycles

Another choice for adaptive bicycles is tandem bicycles. Tandem bicycles have two riders instead of one and, as such, are meant for those who want to ride a bicycle but are unable to power a bicycle by themselves. The second rider is usually an adult without special needs and their job is to help pedal and steer if needed. The Trailmate Double Joyrider is intended for people of all ages and costs about 1,500 dollars per bicycle. This bicycle is interesting as the bikers sit side-by-side instead of one in back and one in front. Both seats come with pedals and adjustable handlebars. This bicycle is unique as one or both riders can pedal; and riders can pedal in sync or out of sync ("Product Categories"). Tandem Bicycles work well for those who are unable to power a bicycle independently, but who may desire to ride a single-rider bicycle. However, riding a tandem bicycle may not give them as great of a sense of freedom as single-rider bicycles.

Tricycles

Tricycles are another type of adaptive bicycle. Tricycles, as the name implies, have three wheels and are more stable than traditional two-wheeled bicycles. The Freedom Concepts Discovery tricycle series was designed with young children in mind, and is intended for those between one and five years of age. This tricycle costs roughly 4,000 dollars and is intended for children with severe disabilities including cerebral palsy and spina bifida. This tricycle has numerous special features, including: full lumbar support with safety belts, optional rear steering, adjustable handlebars, an adjustable seat, Velcro straps on pedals, and a discrete assistance handle ("Freedom Concepts Discovery Mini Tricycle"). Tricycles are really the most diverse of all bicycles and often take components from other types of alternative bicycles. Recumbent tricycles and tricycles with hand pedals are common among adaptive bicycles. Due to their diverse nature, tricycles are the best option for most disabilities but they can attract unnecessary attention. Since tricycles look significantly different than traditional two-wheeled bicycles, they tend to be easily recognizable in a crowd, which can cause people with disabilities to become self-conscious.

Recumbent Bicycles

Recumbent bicycles are a special type of alternative bicycle with seats that provide extra lumbar support. They are most commonly used by those who cannot sit up without support. The pedals are located by the front wheel so a smaller range of motion is necessary. Recumbent bicycles are ideal for people with cerebral palsy because they often have limited range of motion and coordination in their legs. The Mobo Mobito is an example of a recumbent bicycle for children ages four and up, priced around 250 dollars (20 Bikes, Trikes and Tandems for Children with Special Needs). The types of seats used on these tricycles have also been used on other types of adaptive bicycles because they provide extra support for those who are physically disabled.

Handcycles

Handcycles often use recumbent seating and are meant for those who cannot use their legs, such as those who are paralyzed or who have amputated limbs. Differing from the standard bicycle, this bicycle is pedaled by a person using their hands. These bicycles look very different from traditional bicycles as they often have three wheels, are low to the ground, and have pedals located by the handlebars. The 50-HC-0900-SN-AM-9 Hand Cycle with footplate and Snappy Seat works well for children less than three feet tall and costs approximately 620 dollars. This tricycle comes with full back support, a seatbelt, and rest plates next to the wheels for the feet. These rest pedals do not move as the tricycle is pedaled by the child rotating the hand-pedals on the handlebars. There is also a push bar for parents to use when the child gets tired ("Hand/Foot Cycles"). Handcycles provide a great alternative to those with physical disabilities, such as people with amputated limbs and those paralyzed from the waist down, but they require a certain amount of arm strength to pedal.

Quadricycles

Quadricycles are used for those with physical and cognitive disabilities since they provide more stability than a tricycle. Quadricycles are bicycles which have four wheels, providing the most stability. The GC Roam Twinbike Sociable Tandem Quad is an example of a tandem quadricycle and costs about 6,000 dollars from a United Kingdom Online Store. This bicycle does not have any special features for those with physical disabilities, but it has been proven to be useful for those with severe autism because of its extreme stability and available seating for an adult. The shop states that it is very easy to switch out the seats for one more suited to those with cerebral palsy, which means even more people can join in on the fun of tandem biking (Disability Cycles, Buy Bikes Online, Get Cycling Online Cycle Shop, n.d.). Quadricycles are divided into two very distinct categories: tandem and single-rider. The single-rider quadricycles are also useful, but they are really intended for those who can already power a bicycle themselves but need help balancing. Get Cycling, an organization in the United Kingdom that provides handicap bicycles, claims to have great success with the GC Roam Twinbike Sociable Tandem Quad.

There are a variety of adaptive bicycles currently available for people with physical or cognitive disabilities. However, there is not a perfect bicycle for everyone. In the following section, we describe how different modifications affect a bicycle's performance. Understanding how these features function can translate into appropriate and varying bicycle designs catered to the physical and mental abilities of the rider.

V. Bicycle Dynamics

Bicycle dynamics is the study of bicycle motion, particularly from an analysis of the various control parameters. Throughout the twentieth century, numerous studies scrutinized the various aspects of bicycle control and examined different components of bicycle self-stability. Adaptations incorporated into a bicycle's design appear to be dependent on numerous factors, including the bicycle type and the rider's ability level (Moore, Kooijman, Schwab, 2009).

In 1899, mathematician Francis John Welsh Whipple described what would become known as the "benchmark bicycle" (Sharp, 2008). The benchmark bicycle is the model of a bicycle used when analyzing the stability of a bicycle, ensuring that all of the analyses performed were consistent. This was important since slight changes to individual characteristics of different bicycle parts could change the results of the analyses dramatically. According to Whipple, the benchmark bicycle consists of four bodies: the combination of the rider and main frame of the bicycle, a front frame, and two axisymmetric wheels which are able to spin freely and independently of each other (Sharp, 2008). To simplify the analysis, Whipple assumed the tires contacted the ground at a single point and frictional and slip forces were neglected (ibid). According to Sharp, an engineering professor at the University of Surrey Guildford, Whipple's analysis of the benchmark bicycle provides insight into physics of bicycle riding, characterized by instability at very low speeds and by the relationship between steering angle and the lean angle (ibid). Modifications made to adaptive bicycles have to account for these various factors in order to accommodate people with different disabilities.

a. Self-Stabilization & Stability Factors

People diagnosed with Down syndrome, autism spectrum disorder, and cerebral palsy typically struggle with balancing a traditional bicycle, meaning changes must be made to the bicycles to make them more stable. Parameters in bicycle stability include, but are not limited to: the bicycle speed, the angle of lean of the bicycle, the angle of lean of the rider, rider steering inputs, and the angle the front forks of the bicycle make with a vertical axis (Sharp, 2008; Meijaard, Papadopoulos, Ruina, Schwab, 2007). A self-balancing bicycle, for the purpose of this report, is a bicycle which automatically maintains an upright position independent of different rider inputs, such as steering and pedaling (Sharp, 2008; Meijaard, Papadopoulos, Ruina, Schwab, 2007). Modifying a bicycle to make it self-balancing is difficult, but is aided through a number of means. These include installing gyroscopes in the bicycle wheels and maintaining a certain critical speed (Kooijman, Meijaard, Papadopoulos, Ruina, Schwab, 2011). The remainder of section (a) discusses these parameters and their effects on stability in detail. In Table 3 we provide a comparison of the various advantages and disadvantages of the different modifications that can be made to enhance bicycle stability.

Table 3: Stability Modifications

Stability Factors & Modifications	Description	Advantages	Disadvantages
Critical Speed	Speed at which the bicycle is most stable	Does not require modifications	Difficult to attain for beginners Difficult to maintain for people with disabilities
Gyroscopes	Mechanical device which holds an objects spatial orientation constant	Can be installed in bicycle wheels (non-invasive) Aid low-speed instability	Reduced maneuverability at higher speeds
Precession Canceling	Using non-gyroscopic device to cancel wheel precession	Does not affect maneuverability	Requires some modifications to bicycle frame
Rollers	Drum-shaped rollers replace bicycle wheels	Help person with learning disabilities practice balancing Can be modified to suit skill of the rider	Requires extensive modifications to the bicycle frame Difficult to install on adult bicycles
Tire Tread	Changing the tires on the bicycle	Simple installation Variety of tires available	Some tires may not fit the frame Can be expensive
Integrated Electronic Stability Systems	Combining various electronic sensors with control system to enable autonomous stability	Require little input from the rider	Expensive Adds significant weight Complicated integration process

Critical Speed

Whipple's model of the benchmark bicycle illustrates that bicycles traveling at a certain speed are self-stablilizing (Sharp, 2008). This speed is dependent on the length of the bicycle and the acceleration of gravity, and is given by the equation:

$$V = \sqrt{gL} \tag{1}$$

where g is gravitational acceleration, L is the length of the bicycle, and V is the bicycle velocity (Kooijman, Meijaard, Papadopoulos, Ruina, Schwab, 2011). In other words, bicycles are typically least stable when their velocity nears zero, since the rotation of the wheels is also nearing zero, and the gyroscopic effect of the rotating wheel is minimized. This inherent instability at slow speeds contributes to the difficulty many riders face when learning to ride a bicycle.

Gyroscopic Stabilization

Compensation for lack of stability at slower speeds can be accomplished by adding gyroscopes to the inside of bicycle wheels. A gyroscope is a mechanical device consisting of a frame, gimbal, flywheel, and spin axis, where each component spins in its own plane. As the gyroscope spins, the different components of the gyroscope cancel the rotational moments, meaning that the gyroscope maintains the same upright position. When installed in bicycle wheels, gyroscopes reduce the tendency of the wheel to precess, or rotate about its spin axis. This means that bicycle wheels with gyroscopes will maintain a straighter track because the gyroscope will resist the tendency of the wheel to lean left or right as the bicycle slows down.

As with any system, there are limitations to gyroscopic stabilization of bicycles. Since the rotation and precession of the gyroscope is intended to keep the bicycle upright, they tend to impede cornering ability (Kulhavy, 2002). When a bicycle turns at a moderate to high rate of speed, the bicycle-rider system tends to lean at an angle proportional to the severity of the turn and the speed of the bicycle. However, when a gyroscope is mounted inside the bicycle wheels, the bicycle-rider system is unable to lean sufficiently enough to complete a turn at high enough speed, since the gyroscope wants to return the bicycle to an upright riding position (ibid).

Precession Canceling

As discussed above, as bicycle wheels rotate at slow speeds, they are more likely to precess. One method of negating this effect is precession canceling, which involves creating moments which are equal and opposite to the ones created by the wheels. These moments counteract to decrease the tendency of a spinning object to precess as it loses angular velocity. To counteract the precession moments of the bicycle wheels, a second wheel can be mounted above both the front and rear wheels which spins in the opposite direction to and at the same speed as the drive wheels, creating precession moments of equal magnitude and opposite direction (Astrom, Klein, Lennartsson, 2005; Kooijman, Meijaard, Papadopoulos, Ruina, Schwab, 2011). A study conducted at the University of Illinois at Urbana-Champaign (UIUC) showed that a bicycle with precession canceling behaved similarly to a bicycle with gyroscopes (ibid).

Other Factors

Most of the studies involving the stability of bicycles discussed above did not take into account the effects of bicycle tires on stability. Rather, when discussing bicycle dynamics, the contact the bicycle wheels make with the ground is treated as a single point, rather than including the area of the tire that contacts the ground (Doria, Tognazzo, Cusimano, Bulsink, Cooke, Koopman, 2013). However, Doria *et al* show that the tread type and thickness of the tire can have significant effects on the stability of a bicycle. In fact, Doria contends that as the bicycle leans to one side, a thicker tire is less likely to slide out from underneath the bicycle, giving the rider more stability. Likewise, at slower speeds, a thicker tire provides a more stable platform for the rider to balance on since there is more contact with the ground (ibid).

b. Research Projects & Prototypes

Various research projects have been completed which either applied the concept of a self-stabilizing bicycle or which strove to find the relationship between bicycle stability and rider control. For the purpose of our project, we focus on prototypes which employed modifications that do not rely on electronic sensors or controllers.

Prototypes Employing Wheel-Mounted Gyroscopes

As discussed above, one of the modifications which can be made to a bicycle to increase stability is the addition of wheel-mounted gyroscopes. A group of inventors developed a wheel mounted gyroscope that is powered by a rip cord (Murnen, Sigworth, Sperling, 2009). The gyroscope consists of a mass mounted on bearings along the inside of the wheel hub, allowing the mass to spin freely with respect to the bicycle wheel. Rotation of the mass can be initiated by someone pulling a rip cord, similar to those used on lawnmowers, attached to a spring and ratchet system mounted within the wheel; alternatively, a power drill or motor could be used to spin the mass (Murnen, Sigworth, Sperling, 2009). The rotating mass behaves similarly to a gyroscope, canceling the precession of the bicycle wheel and allowing the person riding the bicycle to launch from a stop more easily.

A similar system which utilizes a gyroscope installed in the rear wheel of any two wheeled vehicle was also developed (Patrin, 1987). This system works by mounting the gyroscope to an inner-wheel assembly attached to the wheel spokes (ibid). The design allows the inner wheel and gyroscope to rotate independently of the motion of the outer wheel, meaning the gyroscope will continue to rotate even when the vehicle has come to a stop, simulating the stability of the vehicle when in motion (ibid).

Prototype Replacing Wheels with Rollers

Another adaptation made that can help stabilize a bicycle is replacing the normal bicycle tires with rollers (DiRocco, Klein, Leiberman, McHugh, 2002). Tapered in a barrel-like shape, the rollers allow the rider to lean to some degree, but prevent the bicycle from falling over. As the rider becomes more accustomed to balancing on the center of the roller, different rollers can be added so that they more closely simulate actual bicycle wheels (DiRocco, Klein, Leiberman, McHugh, 2002). One drawback to the rollers is that special modifications must be made to the wheel mounts to accommodate the rollers, and often requires removing the front and rear forks of the bicycle.

Prototype Utilizing an Elastic Cord

At Lund University in Sweden, researchers developed a bicycle utilizing a weighted front wheel and an elastic cord to enhance self-stabilization. Rather than mounting a gyroscope to the front wheel, the added weight would enhance the gyroscopic effects of the bicycle's momentum, making the bicycle more stable at slow speeds (Astrom, Klein, Lennartsson, 2005). Additionally, an elastic band is stretched between the handlebars and the rear of the bicycle frame, making the handlebars return to center after being turned by the rider (Astrom, Klein, Lennartsson, 2005).

A number of means exist for creating a stable bicycle, involving varying degrees of technicality and bicycle modification. The modifications made to a bicycle will depend greatly on the particular skill sets of the rider. What these systems aim to minimize is the amount of effort the rider needs to devote to stabilizing the bicycle. By using a combination of the systems discussed above, a bicycle could theoretically be made which provides enough stability for a person of any skill level to ride. The next section will discuss some of the difficulties associated with obtaining adaptive bicycles for various disabilities.

VI. Issues Adaptive Bicycle Riders Face

Cost, availability and design style are the primary obstacles people with physical and cognitive disabilities face when trying to secure an adaptive bicycle. The cost of a traditional bicycle depends on the type of bicycle a person wants. The large gap in prices between adaptive and traditional bicycles is just one of the reasons alternative bicycles are inaccessible to most people. Since adaptive bicycles require a lot more features than traditional bicycles and the demand is low, the prices for alternative bicycles are very high, as illustrated in section IV of this chapter.

Another common issue for those who are trying to buy adaptive bicycles is availability. Since the percentage of handicapped people who are able to ride and purchase adaptive bicycles is small, there are only a few specialized shops that sell adaptive bicycles. Comparatively, standard bicycles can be purchased at a variety of locations. Those looking to buy adaptive bicycles will likely have to order from a specialty shop online. Adaptive bicycles try to deal with the issues created by a loss of fine motor control.

Lastly, many adaptive bicycles have been extensively modified, making them stand out in a crowd which can, in turn, cause embarrassment to the rider (Lewak, Doree, 2011). These issues of cost, availability, and embarrassment make it hard for people with disabilities to find a bicycle that satisfies their social, physical, and financial needs.

VII. Relevant Organizations & Resources

All of these issues faced by bicycle riders must be taken into account by whoever creates, sells or uses adaptive bicycles. There are many organizations and companies besides our sponsor, Worcester Earn-A-Bike, that work with bicycles. These include athletic, manufacturing, and instructional organizations.

One category of organizations that works with people who ride adaptive bicycles is athletic organizations, such as the Special Olympics. The Special Olympics is the world's largest sports organization for people with intellectual disabilities. A portion of the organization is devoted to bicycle racing that uses adaptive bicycles. This organization recognizes that cycling requires a number of physical feats such as balance and endurance (Cycling, n.d.). Since Special Olympics helps people with intellectual disabilities, they not only teach people how to ride, but also how to prepare for bicycle riding by teaching proper stretching and cool-down techniques.

My Team Triumph is a non-profit athletic program for children, teens, adults and veterans with disabilities. This is a ride-along program, with teams consisting of the challenged athlete who is the captain, and three able-bodied helpers, also known as 'angels' who use specialized equipment provided to guide the captain (Wisconsin Chapter, n.d.). The triumph teams help give someone who would not normally be able to experience a triathlon the thrill of crossing the finish line. My Team Triumph promotes health, teamwork and community by seeing potential in anyone, despite the existence of physical disabilities.

There are other organizations that manufacture and/or sell adaptive bicycles. Most of these organizations help people in their communities by hosting bicycle giveaways or teaching those with disabilities how to use their products. National AMBUCS Inc. is a "non-profit service organization consisting of a diverse group of men and women who are dedicated to creating mobility and independence for people with disabilities" (About Us, n.d.). They are the creators of AmTryke, which is an online therapeutic tricycle manufacturer. AMBUCS held their first official AmTryke giveaway in January 2014, giving away 12 tricycles. However, of the 15,000 plus AmTryke tricycles that have been bought since the company opened, most of them were purchased by AMBUCS volunteers who donated them to financially-needy children with disabilities.

Lose the Training Wheels, newly named ‘iCan Bike,’ is a program sponsored by a national organization called iCan Shine that works with social service agencies and other groups throughout the country to host bicycle camps. Through an intense five-day program, these camps teach those with disabilities who have thus far been unsuccessful in learning to ride a bicycle. They are taught by trained professionals and volunteers on how to use adaptive bicycles. However, there are certain limitations on who is eligible to participate. For example, campers must be under a certain weight and have a certain inseam measurement in order to be eligible (Fitzroy, 2011). These constraints are potential issues that people with disabilities may face when attempting to acquire an adaptive bicycle.

Each of these organizations has taken a different approach to helping people with disabilities. Some organizations provide adaptive bicycle for people with various disabilities, while others work to instruct people with disabilities on how to ride a bicycle. Through this project, Earn-A-Bike strove to further their mission of providing bicycles to the Worcester community by also having adaptive bicycles available for people with disabilities.

VIII. Worcester Earn-A-Bike

Worcester Earn-A-Bike (EAB) is a non-profit organization located at the Stone Soup Community Center in Worcester, Massachusetts, which supplies bicycles to those who volunteer in their shop for a number of hours. Their mission statement is “to teach fun, affordable bike repair to neighborhood youth and community members by providing tools, instruction, and repairable bikes and parts. Earn-A-Bike encourages bicycle riding as an empowering, economical, and healthy alternative to car culture” (About, n.d.). There are two main programs offered at EAB: Youth Earn-A-Bike and Earn-A-Bike 17+ (ibid). Those in the Youth Program only have to volunteer at the shop for five hours, during which they learn the skills necessary to build their own bicycle. Those in the Adult Program have to volunteer for ten hours in the shop before they can use Earn-A-Bike's tools and parts to build their own bicycle. Through these programs, Earn-A-Bike provides inner-city kids with a safe place to go where they can have fun, learn a skill, and help their community (ibid).

Worcester Earn-A-Bike contacted the Worcester Polytechnic Institute's Worcester Community Project Center with a project proposal. Earn-A-Bike had received requests for adaptive bicycles from people with special needs. Earn-A-Bike wanted our group to research alternative bicycles and design a bicycle for riders with disabilities. Specifically, Earn-A-Bike requested that we look into alternative bicycles for adults and wanted us to focus on developmental disabilities such as Down syndrome, autism, and cerebral palsy. In addition, EAB wanted our group to look into ways for the bicycle design to be funded.

IX. Fundraising

In order to build the adaptive bicycle and maintain the capacity to provide bicycles to members of the Worcester community, Earn-A-Bike needed some assistance with raising funds for the adaptive bicycle parts and the manpower to build it. There are numerous approaches a small non-profit organization might take to acquire funding for a specific project. Crowdfunding is one means of funding a project.

Crowdfunding is a form of fundraising which involves receiving small quantities of money from a number of donors (Prive, 2012). Crowdfunding is usually run through an online site. One such fundraising site is Kickstarter, which allows people to donate to a project which interests them. A similar site is Indiegogo, which functions under the same premise. The New York Times describes these sites as "letting designers and other creative people connect with audiences who want to finance their dreams" (Wortham, 2012). Sites like Kickstarter and

Indiegogo are becoming increasingly popular as they provide an easy way for projects to be sponsored. These sites also offer incentives for those who donate, often a free product. Kickstarter has helped over thirty thousand products come to fruition, with donors pledging more than thirty million dollars to projects advertised through Kickstarter (Wortham, 2012).

While Kickstarter and Indiegogo provide a potential method for funding innovations, this fundraising approach has some obstacles. One possible problem with crowdfunding is the potential that a Kickstarter or Indiegogo project will fail to attract attention and consequently not raise any funds. An additional consideration is that when a person or organization starts funding a project on Kickstarter, they become legally obligated to complete that project. If an organization were to give up on the project, Kickstarter has no way to return the pledged money (Wortham, 2012).

X. Conclusion

Bicycles offer a great way to be active while enjoying the outdoors, and serve as a social activity which can be enjoyed with family members and peers. Unfortunately, various developmental and physical disabilities make bicycle riding difficult for some people. As such, alternative designs must be made to accommodate their needs. What may seem a simple task for the majority of the population can be seen as a challenge for adults and children suffering from cognitive and physical disabilities. Based on the disability and the needs and comforts of the rider, alternative bicycles have been developed which greatly benefit a variety of individuals. The next chapter discusses our project methodology, including our project goal, objectives, and the various organizations we contacted while completing our project.

Chapter 3: Methodology

I. Introduction

Various physical and developmental disabilities affect one's ability to ride a bicycle. Often, these disabilities compromise a person's balance, coordination, and physical strength. Since bicycles support a healthy lifestyle, encourage socialization between friends and family, and serves as a great form of transportation; Worcester Earn-A-Bike wanted to be able to provide bicycles that are accessible to people with cognitive disabilities.

After speaking with our sponsors, we gained a better understanding of Earn-A-Bike's goals for the project. There have been several people with disabilities who have come to Earn-A-Bike seeking adaptive bicycles. Previously, the volunteers at the shop had been teaching children with disabilities how to ride bicycles by first putting them on balance bikes, which we discussed in Chapter Two. The time it takes people to learn how to balance varies greatly, especially among those with disabilities. Earn-A-Bike wanted adults to be the target age demographic for our project since volunteers at Earn-A-Bike can teach most children how to ride by using balance bikes. Additionally, for adults there can be a sense of embarrassment when riding an adaptive bicycle, whereas children may not possess the same social awareness. Our sponsors described the experience of one teenage girl with autism. Being a teenage girl, the aesthetics of a bicycle greatly influence the type of bicycle she chooses to ride; she would like to ride a bicycle that does not stand out amongst her peers.

Our research covered a wide range of disabilities, however our project focused on the most prevalent disabilities encountered at Earn-A-Bike: Down syndrome, autism, and cerebral palsy. All of these disabilities are developmental and are associated with difficulty balancing. Our goal was to design a bicycle which is accessible to adults with Down syndrome, autism spectrum disorder, and cerebral palsy. The bicycle we designed had to be safe, comfortable, user-friendly, affordable, and upgradeable so that it may be used by patrons of our sponsor, Worcester Earn-A-Bike. In order to achieve our goal, we developed the following objectives:

1. Identify appropriate modifications that can be made to existing bicycles to accommodate people with Down syndrome, autism, and cerebral palsy.
2. Create bicycle designs which incorporate the modifications identified in Objective 1.
3. Assess the feasibility of the proposed designs in terms of cost, materials, and fabrication.
4. Prototype the most feasible design.
5. Identify potential sources of funding for Earn-A-Bike.
6. Determine how to educate the Earn-A-Bike community on adaptive bicycles.

The following sections describe these objectives and how we accomplished them.

Designing the bicycle was the main focus for our project. The next section describes how we obtained information on the appropriate modifications we made to a standard bicycle.

II. Identify Appropriate Modifications for Target Disabilities

In order to determine the modifications we needed to make to the bicycle, we conducted research into the advantages and disadvantages of products already on the market. We also conducted a number of interviews with members of different cycling communities and organizations. We chose this methodology to gain knowledge from various organizations since they have experience with the topic. For the larger organizations, we conducted our interviews via e-mail and phone. For local organizations, we generally met with employees and volunteers in person. We also worked with the members of Earn-A-Bike to determine what resources were available to us.

When determining which modifications to make to a bicycle, we had to consider the needs of people with cognitive disabilities, the aesthetics of the design, and the fabrication, materials, and cost required to build the bicycle. Balance is the primary stumbling block for people with Down syndrome, autism spectrum disorder, and cerebral palsy. Consequently, we focused much of our exploration of modifications on ways to make an adaptive bicycle more stable than a traditional bicycle while maintaining as much of the aesthetics of a traditional bicycle as possible. In addition, we interviewed people with disabilities and their caretakers to learn more about what modifications they would like made to their own bicycles. We also interviewed members of various organizations which cater to these disabilities, including Special Olympics, Bicycle Man, AmTryke, My Team Triumph, Boston College Campus School and the Cotting School. These organizations were chosen because of their active involvement in providing or working with adaptive bicycles for people with disabilities. The interview questions we used for each are provided in Appendix A.

Through interviewing our sponsor, we determined that, particularly for teenagers with developmental disabilities, how different their bicycle looks from their peers can have a significant impact on self-perception. To assess the importance of aesthetics to teens and young adults, we interviewed Earn-A-Bike shop managers and the families of children with disabilities who wanted adaptive bicycles. Through these interviews, we gathered information regarding which modifications teenagers and adults wanted on their own bicycles. Then, based on trends in the interviewees' responses, we developed an appropriate design.

Our sponsor also put us in contact with several volunteers at Earn-A-Bike who either personally used adaptive bicycles or had family members that did. Our group held interviews with these volunteers and their families so that we could learn about their personal experiences with bicycles they ride, issues they have with traditional bicycles, and what they would like to see in an adaptive bicycle.

Special Olympics, a non-profit organization which provides recreational and athletic competitions for people with disabilities, sponsors bicycle teams throughout the country. Each of these regional teams has a number of cycling coaches who assist the members of the team with disabilities. We interviewed one cycling coach from a local team, the Auburn Rockets, to obtain information on what adaptations are made to the athletes' bicycles. We also gathered information on common issues associated with very specialized adaptive bicycles. Additionally, we interviewed the cycling coach to gain a sense of the social and physical benefits of bicycle racing for people with cognitive disabilities.

We also contacted members of AMBUCS Inc., a non-profit organization which owns the adaptive tricycle manufacturer AmTryke, to learn which modifications are the most effective for their target demographic, which consists of people diagnosed with Parkinson's disease, multiple sclerosis, and stroke victims. We interviewed one member of AmTryke, who is also involved with Bicycle Man LLC., who discussed alternative designs which would also cater to those disabilities. The purpose of contacting members of AmTryke was to learn about their process for determining which design elements to include on an adaptive tricycle.

Interviewing members of My Team Triumph mainly provided insight into the social benefits of participating in a race. Since the athletes who participate tend to be severely disabled, most are pushed to the finish line in specially modified carriages. My Team Triumph members revealed how their disabled athletes benefit from the help of the "Angels" who push them across the finish line in adapted push chairs. These findings lead us to information such as which modifications might help with comfort, ease of use, and performance of our adaptive bicycle. Since members of My Team Triumph are typically involved with endurance events, they had viable information regarding the long-term usability of modified bicycles as well.

We also chose to interview members of special needs schools in Massachusetts, specifically the Cotting School and the Boston College Campus School. For each school, we contacted the physical therapists, who use bicycles as a form of therapy for children with disabilities. We contacted them to learn about the health benefits of bicycling and the types of bicycles they use with their students.

The next section describes how we used the information gained from our interviews to determine which modifications were feasible to make to our bicycle given the needs of the various disabilities and the resources at our disposal.

III. Develop a Feasible Adaptive Bicycle Design

In order to assess the cost of designing an alternative bicycle, we began by researching adaptive bicycles already on the market, as well as the cost of specific modifications that could be made to traditional bicycles, such as gyroscopic wheels. We also analyzed how easily someone would be able to repair an adaptive bicycle, since it will be primarily utilized by community members. Our initial research revealed that the cost for adaptive bicycles tends to be significantly higher than for traditional bicycles. Since Earn-A-Bike is a non-profit organization, our design needed to be cost effective and easily fabricated. The parts and bicycles at Earn-A-Bike are all donated, therefore the design modifications we chose to make had to be made using the tools and parts available at the shop.

The actual bicycle design began with hand-drawn sketches of potential designs for new bicycles and adaptations that could be made to existing bicycles. For each design, we had to determine how expensive the bicycle would be to build and how extensive the custom fabrication work would be. The cost of the design was mainly analyzed by examining what additional parts would be needed or if the parts were readily available at Earn-A-Bike. Additionally, since our adaptive bicycle was based off of a traditional bicycle frame, each design required a level of fabrication to make the design functional. The extent of the fabrication required, like the cost of the bicycle, was greatly determined by the parts needed and whether they were available at Earn-A-Bike or would have to be purchased. Another cost factor was the number of hours required to build the bicycle. Once a particular design was deemed both cost effective and mechanically feasible, we built a prototype of the design.

Interviews were again our primary method of gathering information on the feasibility of different modifications, with researching commercially available designs being our secondary approach. Additionally, we looked for common themes suggested by the people and organizations we interviewed in order to solidify the plans for our bicycle design. This included similarities in the types of modifications people with disabilities wanted to be made to their bicycles and what they wanted their bicycle to look like. In the next section we discuss different sources of funding the Earn-A-Bike could use to build more adaptive bicycles.

IV. Sources of Funding for Earn-A-Bike

Parts for adaptive bicycles are different from and less widely available than those of a standard bicycle. Earn-A-Bike's ability to build and maintain these adaptive bikes is important, but as a non-profit organization this task may be costly. For this reason our project team incorporated a fundraising plan into the project goal. Our research revealed the high costs required to upkeep such advanced bicycles, and our team aimed to help Earn-A-Bike identify potential sources of funding.

In order to determine the most viable sources of funding for Earn-A-Bike, our team consulted with our sponsors and conducted research into various funding options. We researched forms of online crowdfunding, discussed in our literature review, as well as local and national organizations which provide grants for non-profit organizations. We then compiled a spreadsheet of all applicable organizations which Earn-A-Bike could reference for future project funding.

V. Community Education

Since one goal of Earn-A-Bike is to provide bicycles to all members of the community, our team developed a means for Earn-A-Bike to educate the community about adaptive bicycles. Since Earn-A-Bike did not have much experience with adaptive bicycles, our group created a brochure which contained information about various adaptive bicycles and how these bicycles help those with cognitive disabilities learn to ride. Included with this informational brochure are programs for people who ride bicycles and resources for families to purchase adaptive bicycles.

To complete this brochure, our team considered which methods of disseminating information on adaptive bicycles to the Earn-A-Bike community would be the most effective. We then decided what information would be most useful to community members, such as the adaptive bicycles we wanted to include, which organizations provided adaptive bicycle programs, and ways families could afford adaptive bicycles.

VII. Conclusion

Utilizing these objectives, we developed an adaptive bicycle for people with developmental disabilities, a funding plan for future adaptive bicycle projects, and a means of educating the community on adaptive bicycles. Reaching out to other organizations in the cycling community allowed us to gather important information on commercially available adaptive bicycles as well as adaptations we could incorporate in our prototype. Speaking with community members helped us understand the difficulties people with disabilities have with riding traditional bicycles. Our efforts also made it possible for Earn-A-Bike to provide bicycles and additional resources to all members of the community. The following chapter describes our findings from the interviews we conducted as well as the results of our design and prototyping process.

Chapter 4: Findings & Results

I. Introduction

In the following chapter, we describe developing an adaptive bicycle for people with Down syndrome, autism spectrum disorder, and cerebral palsy. After successfully identifying the issues that those with our target disabilities faced when riding traditional bicycles, we identified financially feasible adaptions that could be made to a bicycle, and then created several adaptive bicycle designs incorporating those adaptions. We selected a final design based off of our assessments of each proposed design. We also created a funding plan for Worcester Earn-A-Bike so that they can continue to build adaptive bicycles and complete other cycling projects. Our design will give people with cognitive disabilities the opportunity to participate in a variety of activities they could not before, and means for Earn-A-Bike to provide bicycles for all members of the Worcester community.

II. Social & Psychological Barriers to Bicycle Riding

Before we determined which modifications we would make to a bicycle, we conducted a number of interviews to gather information on what the most common issues associated with bicycling were for people with Down syndrome, autism spectrum disorder, and cerebral palsy. We interviewed a number of individuals, including people who are members of the Earn-A-Bike community and have family members with disabilities, a Special Olympics cycling coach, physical therapists from the Cotting School and Boston College Campus School (BCCS), and various other members of the bicycling community. Through these interviews and our research, we found that the primary social and psychological concerns for people with disabilities riding a bicycle were fear and self-perception.

Some People with Disabilities Have a Fear of Bicycle Riding.

One common theme we found among the disabled riders and their families that we interviewed was fear of riding a bicycle induced by a traumatic event. For example, we interviewed one member of the Earn-A-Bike community whose daughter is diagnosed with Down syndrome. She explained that once her daughter outgrew her childhood tricycle, the daughter seemed to lose interest in riding. The mother attributes this loss of interest to a fear of the bicycle falling over because the daughter no longer fits comfortably on the bicycle.

In an interview with a Special Olympics cycling coach, we learned that his daughter, who is diagnosed with a cognitive disability on the autism spectrum, fell off of her bicycle during a race and broke her wrist. At the time, the daughter was riding a bicycle with adult training wheels, which created a wobble effect as the daughter was racing, causing her to lose balance and fall over. Since then, she has not ridden a bicycle due to fear of having another accident during a race. Similar instances were also discussed in our interviews with physical therapists at local special needs schools. In each instance, the bicycle accident led to a decline in rider confidence and inhibited their desire to ride bicycles.

Bicycle Aesthetics are Important to Teenage and Adult Riders.

For all teenagers, appearance can change everything. This is no different for teenagers with cognitive disabilities. One gentleman we interviewed, who is a personal friend of our sponsor, had a teenage daughter who was diagnosed with a disability on the Autism spectrum. He described how his daughter refused to ride her adaptive bicycle because it looked significantly different than her brother's and her friends' bicycles. The heavily modified frame, smaller rear wheels, and wide stance made the bicycle easily distinguishable among traditional bicycles. Of the other interviews our team conducted, each individual we spoke to agreed that the looks of adaptive bicycles can have a significant impact on self-confidence and self-image, particularly for young adults.

III. Physical Barriers & Design Considerations

In addition to gathering information on the social and psychological aspects of cycling for riders with disabilities, our research and interviews also revealed a number of bicycle design factors that affect someone with a disability's ability to ride a traditional bicycle. These design considerations include the height of the bicycle, the bicycle gearing, and the braking system used, all of which impact a rider's balance to varying degrees.

Seat Position and Height can Impact a Rider's Ability and Willingness to Ride.

The Special Olympics cycling coach from the Auburn Rockets, explained that very often the bicycles that the athletes on his team use have a low enough seating position that the athletes can firmly plant their feet on the ground while seated. This claim was also verified through our interviews with the families of people with disabilities and with the physical therapists from the Cotting School and Boston College Campus School. The reason the lower seating position is preferred is because it inspires rider confidence and increases accessibility. For example, on a traditional bicycle, the rider typically has to dismount the seat in order to plant his or her feet on the ground. People with cognitive disabilities or balance problems may not be physically able to constantly mount and dismount the bicycle seat, especially when coming to a stop. Additionally, having a lower seating position and step-through frame design allows the rider to get on the bicycle without having to step over the tall frame, keeping the rider's feet as close to the ground as possible.

Minimizing Available Gears Simplifies Riding the Bicycle.

Another aspect of the bicycle that affects rider accessibility is the gear ratios used. Typically, riders are most stable when the bicycle is moving or when they are pedaling. For this reason, the Special Olympics cycling coach discussed that having easier gears allows the rider to continue pedaling even on steep inclines, keeping the bicycle moving forward and therefore more stable. This can be accomplished by "locking out" the bicycle gears, which means making the more difficult gears inaccessible, or by simply limiting the number of gears on the bicycle. The bicycling coach also mentioned that the concept behind gearing can be difficult for people with cognitive disabilities to fully comprehend, and they are often unable to select the proper gear for a given situation.

We interviewed a gentleman recommended to us by our sponsor whose daughter is diagnosed with Asperger syndrome, which is on the autism spectrum. He mentioned that his daughter was unable to shift gears, so he bought her fixed gear bicycles. Additionally, the type of shifting mechanism used can have an impact on usability. The bicycling coach and our sponsor discussed that twist-shift mechanisms can be difficult to use because they require the rider to adjust his or her grip on the handlebars, and that these shifters can be difficult to repair. Instead, both interviewees recommended using thumb-shifters because they are easily reached by simply extending one's thumb.

Brake Design can Improve the Bicycle's Ease of Use.

The types of brakes used on our adaptive bicycle will also impact a person with a disability's ability to ride the bicycle safely. Through our interviews with the Special Olympics cycling coach and the physical therapist at the Cotting School, our team found that hand brakes are the most effective for people with disabilities. The other types of brakes commonly used are coaster brakes, which engage when the rider pedals in reverse. Since our target disabilities are cognitive disabilities, both of the interviews mentioned above revealed that the concept of pedaling backwards to stop can be difficult to grasp. However, hand brakes allow riders to brake easily without changing their grip on the bicycle, adding to rider confidence and ease of use.

Cost of Adaptive Bicycles Reduces Accessibility.

Lastly, our numerous interviews and research into the commercial adaptive bicycle market revealed that adaptive bicycles are often unavailable to people with disabilities because of cost and a limited range of bicycles built for adults. As discussed in our literature review, adaptive bicycles can cost thousands of dollars depending on the severity of the disability. Each of the individuals we interviewed expressed their concern that our design must be affordable if it is to be accessible to everyone. Another issue cited was the inability to transport some of the more heavily modified adaptive bicycles available commercially. The Special Olympics cycling coach discussed how he is unable to transport adaptive tricycles to or from races without help because the bicycle does not fit in any of his vehicles.

Each of these physical barriers and design considerations is influenced by the severity of a person's disability. Our team considered these factors in order to make our bicycle accessible to as many people as possible. Based on the social and physical issues that those with our target disabilities face, our group identified what modifications were needed for them to feel comfortable on bicycles. The implantation of these design considerations is discussed in detail in the following sections.

IV. Proposed Adaptations and Design Assessment

Each of the aforementioned issues was addressed to varying degrees in our bicycle design based off of what our team believed would represent the best compromises. Specifically, we explored the feasibility and appropriateness of implementing gyroscopic wheels, using crank forward bicycle frames, making unique A-Frame attachments, and building a slim tricycle. Each design attempted to solve several problems that people with Down syndrome, autism, or cerebral palsy face when riding bicycles. Therefore, we assessed each design based on how well the design would accommodate people with various disabilities. Factors such as balance, ease of use, and aesthetics were all considered for each design.

Additionally, we evaluated the cost of the each design and the approximate work required to build each design. Based on the evaluations, we picked our final design. We started by creating a rough estimate of the cost of each design. Most of the basic bicycle parts and tools were provided by Earn-A-Bike, therefore we evaluated the costs of each design based purely off of extra parts the design required that could not be provided by Earn-A-Bike. It was very important that costs for our design were as low as possible because Earn-A-Bike is a non-profit organization.

Implementing Gyroscopic Wheels Would Solve all Issues of Balance and Aesthetics, but are Expensive and Maintenance Intensive.

Initially, based on our research, our team wanted to implement gyroscopic wheels into our design. As described in Section V of the Literature Review, a gyroscope is a mechanical device consisting of a frame, gimbal, flywheel, and spin axis, where each component spins in its own plane. As the gyroscope spins, the different components of the gyroscope cancel the rotational moments, meaning that the gyroscope maintains the same upright position. Since gyroscopes decrease the tendency of the wheel to lean left or right, the bicycle is less likely to tip or fall, stabilizing the entire system. Our research also showed that this effect makes pedaling and stopping easier because in each case the rider has more idle time to pause and regain balance, or to put his or her feet on the ground without falling over, since the motion of the gyroscope simulates the wheels moving.

Gyroscopic wheels were a concept that we thought would work well for our bicycle, but the cost of the gyroscopic wheels was too great since gyroscopic wheels are a relatively new technology being applied to bicycles. Additionally, most gyroscopic wheels available are made for children's bicycles, while our design is aimed at teenagers and adults. After researching online, the largest-diameter commercially available gyroscopic wheel was 20" in diameter. The typical adult bicycle tire is 26" in diameter, but 20" can be used for a young teenager or a shorter adult. Our team found that a standard bicycle wheel gyroscope would cost around $120 per wheel (Bicycle Wheel Gyroscope). If our group wanted a gyroscopic wheel specifically for adult bicycles, we would have needed to fabricate a custom gyroscope.

Crank Forward Bicycles Provide an Excellent Base for an Adaptive Bicycle, However the Frame Required Extensive Custom Fabrication.

Crank forward bicycles are a different take on traditional bicycle design we found during our research which was also suggested to us by an AmTryke employee. These bicycles, also called flat-footed bicycles, were created to be more rider-friendly than traditional or recumbent bicycles. Crank forward bicycles have elongated frames, full-sized wheels, and large seats that sit further back on the frame, but vary when it comes to handlebar and stem design (Bryant, n.d.). Crank forward bicycles have several benefits, which provide possible solutions to multiple issues. For one, due to the further-back and therefore lower seat, the rider can put his or her feet flat on the ground once the bicycle comes to a stop. This helps with the issues of balance and height of traditional bicycles, and may also assuage the worries of an apprehensive rider. Being able to have one's feet planted comfortably on the ground can also aid braking for anyone who might not be able to grasp the idea of hand brakes. The seat placement also provides for a more upright sitting position, which is better for the back and overall posture of the rider, causing virtually no pain in the wrist, arms or neck. In addition, the large seat gives more support to the rider's bottom. Lastly, crank forward bicycles look very much like standard two-wheeled bicycles because of their average wheel size and Mountain Bike style tires, which would appeal to anyone who is largely concerned with the aesthetics of their bicycle (Bryant, n.d.).

In order to implement the crank forward bicycle design, our group would have needed to modify the entire frame of the bicycle or purchase a used bicycle frame. After conducting some research, our group realized that it was very difficult to locate frames of crank forward bicycles. Therefore we based the estimated cost of buying an entire crank forward bicycle. Based on a quick internet search, we determined the cheapest crank forward bicycle would cost around $240 without shipping and handling from ebay (New 26" 7 SPEED beach cruiser bicycle bike forward crank CA520). If we had chosen this design to prototype, no additional parts would have been needed to be purchased since Earn-A-Bike has all the materials required for this bicycle in stock. This design could have been implemented by modifying the geometry of an existing bicycle frame and replacing the handlebars, which could have been accomplished using bicycles already available. However, the extent of the modifications which would have been made to the bicycle frame would have required a significant amount of time and fabrication, limiting this design's feasibility for our project.

A-Frame Attachment with Full-Sized Bicycle Wheels Would Help Balance but Would be Aesthetically Unpleasing.

Another idea for a modification, which our team called an A-frame attachment, was discussed during our first meeting with one of our sponsors. This is an attachment which could be mounted onto a standard bicycle using a rear seat rack. The A-frame would have attached training wheels that stem all the way down from the seat post instead of the rear wheel axle. This design would be extremely beneficial for any balance issues, and would help with braking since it would not fall over when coming to a stop. Though this modification would be slightly more noticeable as an adaptive bicycle than a crank forward, standard sized wheels would be used as training wheels.

For this design, a standard bicycle would be used with the A-frame attached to a bicycle rack on the rear triangle of the bicycle. Since there are many standard bicycles available at Earn-A-Bike, our team would have used one of those for this design. The A-frame attachment would be built using the rear stays off of a donated bicycle at Earn-A-Bike. Using an older bicycle frame made of steel would ensure that the stays would be strong enough to prevent bending. This means the main cost for implementing this design would be purchasing the adult training wheels that would attach to the A-frame. Our team determined the best option for adult training wheels would be the Sunlite HD Adjustable Training Wheels, available for $65 from BicycleBuys.com (Sunlite HD Adjustable Training Wheels 20-26"). There would no additional costs as all tools and other bicycle parts needed are available at Earn-A-Bike.

A Slim Tricycle With Wheels in Between the Rear Stays Would Most Closely Resemble a Traditional Bicycle and Could be Built Using Donated Bicycle Parts.

We developed the next design with the help of the man whose daughter was the inspiration for our project. Essentially a slim tricycle, this idea includes modifying the rear stays to fit two standard-sized wheels in between the rear stays. Depending on the needs of the rider, the rear wheels could be placed either closer together or further apart. Spreading the wheels apart would provide a wider base, making the bicycle more stable for individuals who need additional support. This design solves problems with balance, since the dual rear wheels would make the bicycle difficult to tip over. Having a bicycle that can stand on its own also eliminates the possibility of falling and gives the rider one less thing to concentrate on, thus allowing the rider to focus on steering or braking. Another huge plus of this design is that, from either side, it would look very similar to a traditional bicycle because we are using full sized wheels. Depending on the distance between wheels, a large fender or basket could be used so that even from the rear, the bicycle could look traditional.

Below is a comparison of the advantages, disadvantages, and estimated costs for each design. While it is clear that some designs are more costly than others, all of these prices are rough estimates. For instance, if our group had chosen the crank forward bicycle design, then we could eliminate its large price tag by fabricating the frame ourselves from donated bicycle parts. For this reason, simply evaluating the prices did not give us a clear idea of which design to proceed with as there were many other factors to examine. Therefore, Table 4 also compares each of these suggested designs in terms of what problems they solve and how easily a bicycle could be modified to incorporate the design.

From this assessment, it is obvious that the cheapest bicycle is not necessarily the easiest and fastest bicycle to make, and vice versa. Our group concluded that the deciding factor for the final bicycle design selection would be which design solved most of the issues that those with our target disabilities face and could be safely used every day with little complication.

Table 4: Assessment of Proposed Designs

Modification	Pros	Cons	Cost
Gyroscopic Wheels	-Gyroscopes help keep wheels upright -Simulates effects of spinning wheel, even when at a stop -Added stability aid rider when braking -Bicycle frame unchanged -Looks like standard bicycle -Uses handbrakes -Gears can be locked out	-Limit the rider's ability to lean into a turn -Expensive to purchase and difficult to fabricate	Materials Needed: -2 Wheels Approximate Cost: $240
Crank Forward Bicycle	-Seat lower to ground -Keeps the rider more upright, improving rider posture and limiting stress on the arms, wrists, and lower back -Upright seating, pedal placement, and frame allow for better balance -Looks like traditional bicycle -Uses handbrakes -Gears can be locked out	-Still only two wheeled, so it would not help individuals who are more severely disabled - Requires extensive custom fabrication	Materials Needed: -Bicycle Frame Approximate Cost: $240
A-Frame Attachment	-Ensures extra balance -Attachment can be placed on any person's bicycle -Any tire type can be mounted on the A-frame -Handbrakes can be used -Gears can be locked out	-Does not look like a standard bicycle -Adult bicycles with training wheels tend to experience a 'wobble' effect which can cause the bicycle to tip -A-frame may bend or warp depending on rider weight	Materials Needed: -Adult Training Wheels Approximate Cost: $65
Slim Tricycle	-Provides extra stability -Will look like a normal bicycle from the side due to full-sized wheels -Handbrakes can be used -Gears can be locked out	-The design is a tricycle which means it does not look like a standard adult bicycle from all angles -Requires modifying the width of the rear stays to fit two wheels in between them	Materials Needed: -Donated Bicycle -Additional bicycle wheel Approximate Cost: $0

VI. Design Prototype

a. Final Design Selection and Description

When creating our adaptive bicycle design, there were a number of design criteria which influenced our final prototype. As discussed above, the most crucial criteria which our design had to meet were affordability, material availability, and safety. After assessing each of the proposed designs, our team decided to move forward and prototype the slim tricycle design. The slim tricycle design offered the best solutions for the issues that those with cognitive disabilities encounter when riding a bicycle. However, we did not proceed with the aforementioned slim tricycle design, which placed both wheels between the rear stays. This design would have required modifying a bicycle frame by cutting and spreading the rear stays farther apart to accommodate both wheels. Since we wanted instead to make a prototype which could be attached to any bicycle, we redesigned our slim tricycle prototype. The main components of the design and how it meets each of our design criteria are discussed below. The detailed steps of the fabrication process are discussed in Appendix C.

The Slim Tricycle was the most Affordable Design Since Major Components were Readily Available at Earn-A-Bike.

Our prototype of a slim tricycle proved to be the most cost efficient adaptive bicycle design because it was built almost entirely of traditional bicycle parts. In order to form the foundation of the rear axle, three steel bottom brackets were cut from scrapped donated bicycles at the Earn-A-Bike warehouse. By using bicycles from the warehouse, we avoided the cost of purchasing new or used bicycle frames to cut the bottom brackets from. The bottom brackets already contain their own axles, which rotate freely on internal bearings. This eliminated the need to purchase or fabricate custom bearings for our axle. Additionally, the bicycle frame we attached our rear axle to was from a donated bicycle, saving us the cost of purchasing a bicycle frame. The brakes, shifter, derailleurs, chain, wheels, and handlebar were also all donated parts readily available at Earn-A-Bike.

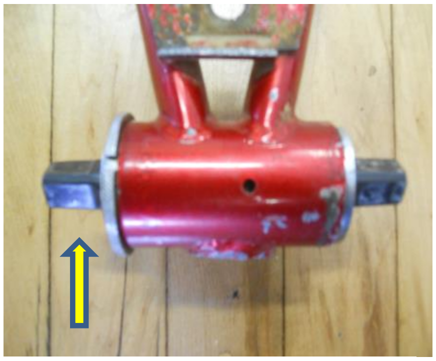


Figure 7: Depicts a bottom bracket with crank axle.

Completing our design did require some expenses, which were primarily incidental shop materials. Cutting the bottom brackets from the bicycle frames required the use of an angle grinder, for which we needed to purchase a cutting wheel. Aligning and connecting the bottom bracket axles together on the drive side required using an M8 fine threaded 3/8” bolt, which also had to be purchased. The sleeves which make up the axle components consisted of square stock steel on the drive side and round stock steel on the non-drive side. While these pieces of steel were available at one of our sponsor’s shops, these pieces would normally need to be purchased. Similarly, the welding materials were also available at our sponsor’s shop, not at Earn-A-Bike, meaning that if someone were to build our prototype they would need access to a metal shop.

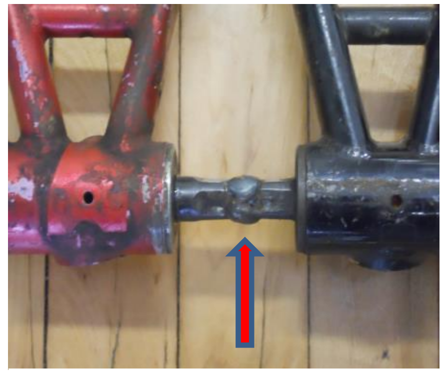


Figure 8: Welded connection between bottom brackets on drive side.

The total cost required for our group to complete the prototyping of the design was $2.25. This price is based off of the hardware we needed to purchase, but does not include the cost of expendable shop materials or the additional steel used. A detailed parts list is provided in Appendix B, which includes the parts used, where they were purchased, and the cost of each part.

Figure 9: Bottom bracket with attached seat stays.

Our Design Used Steel Bicycle Parts for Strength.

Since one of the criteria for our bicycle prototype was safety, we used steel bicycle frames and components. By using bottom brackets, we ensured that the axle would be strong enough to handle the weight of a rider since the bottom bracket is the strongest part of a bicycle frame. We also used the seat stays on the center bottom bracket as a mounting point to attach our prototype to the rear dropouts of a bicycle. Additionally, the attachment was mounted as near to the dropouts as possible to prevent the mounting point from bending due to the stress of riding.

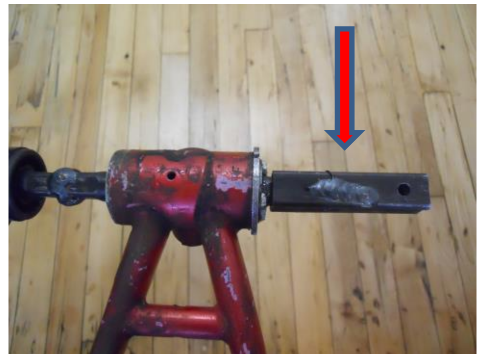


Figure 10: Square stock steel sleeve welded onto bottom bracket axle.

To create the axle of our attachment, we welded connections between the axles contained within the bottom brackets. On the drive side, we used square stock steel to ensure a tight fit between the axle contained in the bottom bracket and the attached wheel. On the non-drive side, we used round stock steel with a threaded internal sleeve which the wheel axle would thread into. We also kept the axle relatively short to reduce bending stresses on the axle components and on the bearings within the bottom brackets. Wheels with steel hubs were also used to ensure the bearings with the wheel hubs would not fail due to extreme stresses.

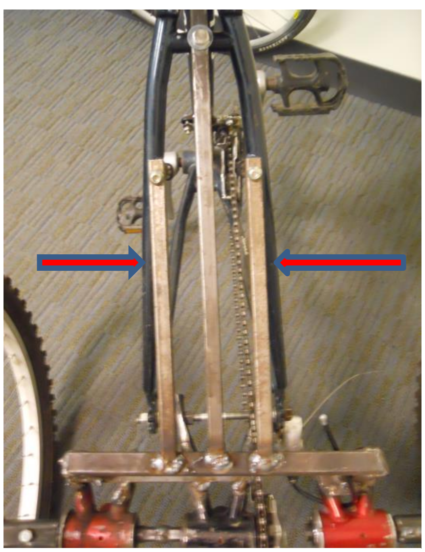


Figure 11: Depicts rear stays which support the axle.

Additionally, to ensure the prototype connected securely to the rear of the bicycle, we fabricated additional steel stays which connected to the rear brake mounts. We used steel square stock welded to our axle with holes drilled through the ends so that the stays would fit over the brake mounts. This provided additional strength for our prototype, keeping the axle from flexing or pivoting in the dropouts. These stays also help distribute the load on the axle to reduce the amount that the axle flexes. Since the stays attach to the rear brake mounts, no additional holes or mounting points need to be added to the bicycle frame, keeping the frame intact.

Our Prototype was Designed to Incorporate Components which Targeted the Needs of People with Down Syndrome, Autism, and Cerebral Palsy.

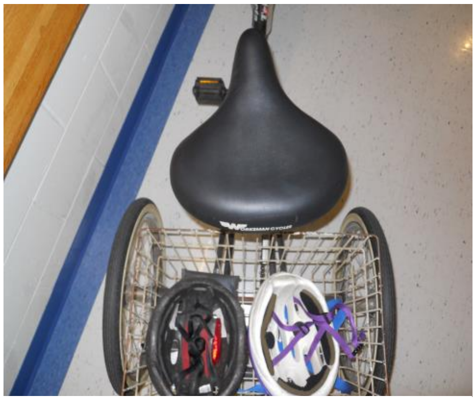


Figure 12: Large seat shown on adaptive bicycle at the Cotting School.

As discussed in section three of our findings, there were a number of bicycle design criteria which we needed to meet in order to make our prototype accessible to our target disabilities. These included a wide seat for added rider support, handlebars which promoted an upright seating position, handbrakes instead of coaster brakes, and limited gears for ease of use.

The seat we chose was based on the seats which were used on the adaptive bicycles used by the physical therapists at the Cotting School. Taking from a cruising bicycle, the seat is very wide and cushioned, which helps rider comfort especially during extended riding. Additionally, for people with cognitive disabilities who are afraid to ride a bicycle, the wider seat provides more support, potentially improving their confidence.

Figure 13: The handlebars (red) and wide seat (yellow) promote an upright and supported seating position.

Our prototype's handlebars were taken from a BMX style bicycle, which are slightly swept back so that the rider can sit more upright. As discussed in our literature review, a more upright seating position can help improve balance. Also, an upright seating position reduces stress on the arms, wrists, and lower back (Benjamin, 2004). Especially for people with cerebral palsy, who typically suffer from muscle tone abnormalities and decreased strength, sitting more upright will keep the rider more comfortable as well as keep the rider more stable. Having less stress on the wrists and back will also help individuals who have weak or arthritic joints ride the bicycle comfortably.

As discussed in our design considerations, handbrakes are generally considered the best brakes to use for individuals with disabilities. The Special Olympics cycling coach, special needs schools physical therapists, and individuals whom we interviewed all agreed. Therefore, our design utilizes handbrakes to ensure that the people riding our bicycle will be able to stop safely. Additionally, since our bicycle's drive wheel has a freewheel cassette attached the individuals who ride our bicycle will not need to learn how to pedal in reverse.

Figure 14: Freewheel cassette.

Gearing is another important design consideration that our group considered when developing our final design. Since we wanted our prototype to attach to any bicycle frame, we knew that some bicycles have front gears which we would not be able to modify. For that reason, our prototype only has one gear attached, so that the number of gears is only dictated by the number of front gears on the donor bicycle. Additionally, since our attachment only has one gear, the rear derailleur will need to be used to tension the chain if the bicycle it is being attached to has front gears. Since gears can be difficult for some people with disabilities to use, the existing gears on a bicycle can

Figure 15: Shows connection between the drive wheel and the drive side of the axle (yellow), with single gear (red).

be locked out as discussed previously, meaning the rider will only have access to some or none of the additional gears. However, for riders who are able to use gears, having the three front gears to choose from can help the rider ride smoothly in a variety of situations, such as changing to a lower gear to go up a hill.

One additional modification we employed in our design was the use of mountain-bike style tires. The aggressive treads and added width provide additional traction and stability, since more surface area of the tire contacts the road surface. Also, the mountain bike tires add to the aesthetics of the bicycle, further disguising the look of the tricycle.

Our Prototype Tricycle Design will be Accessible to a Number of Individuals.

Based on the materials, cost, and time constraints of our project we developed our adaptive slim tricycle attachment to be used as a prototype by Earn-A-Bike for future adaptive bicycle projects. The main component of our design which makes our prototype accessible to a number of individuals is that it can be attached to any traditional bicycle frame to transform the bicycle into an adaptive tricycle. This means that, even if a rider is not seeking an adaptive tricycle, the attachment can be used for demonstration purposes to show the rider the benefits of adaptive bicycles and what can be produced by Earn-A-Bike. The tricycle design means that people with disabilities can ride the bicycle and make their own determination as to whether they would like a similar bicycle, and provide potential feedback to Earn-A-Bike to further improve the design.

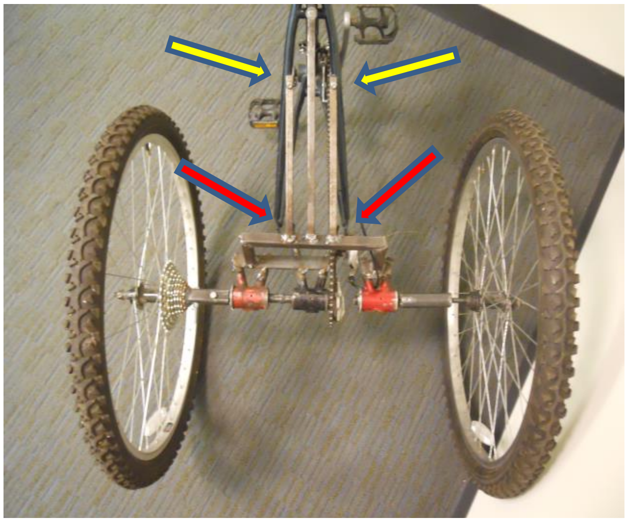


Figure 16: Shows the detachable rear axle, with mounting points on the dropouts (red) and brake posts (yellow).

Since aesthetics were also an important component of this design, we used a few design cues to attempt to make the prototype look as near to a traditional bicycle as possible. One simple way we accomplished this was by using full-size bicycle wheels, which mask the tricycle axle when viewed from the side. Also, since the front wheel is also a twenty-six inch wheel, the prototype looks more a like a traditional bicycle than most tricycles available on the market, which tend to use smaller wheels on the rear axle. The length of the axle was also minimized to ensure the tricycle was as slim as possible given our design constraints of cost, materials, and fabrication time. Our final total width, measured from the outside of one wheel to the outside of the opposite wheel, was twenty-five inches. This length was chosen because it not only provided the most strength for our design, but also because it minimized the degree to which the design stands out among other bicycles.

Figure 17: Side view of bicycle with our prototype attached.

b. Issues Encountered During Prototyping

During the prototyping and fabrication phase of our project, our team encountered some unexpected difficulties resulting from the fabrication methods used. These included material and equipment limitations, as well as additional design specifications and considerations.

The Fabrication Required Specialized Equipment that not Everyone can Access.

In order to build our adaptive bicycle prototype, we needed access to equipment and tools not available at Earn-A-Bike. These included welding materials, angle grinders, and scrap steel.

One of our sponsors, Scott Guzman, had access to a metal workshop which provided us the necessary equipment to build our prototype. For example, while WPI has a welding shop and other machine shops, none of our group members had access to the WPI machine shops. Therefore, we required the use of our sponsor's shop in order to fabricate the bicycle. Additionally, the shop we used to build the bicycle also had the available round and square stock steel required to form parts of the axle, as well as the angle grinder used to cut the bottom brackets from the bicycle frames.

Figure 18: Our Sponsor, Scott Guzman, and Bror Axelsson working on the prototype at Scott's metal shop.

Fabrication Techniques Caused Unexpected Delays while Building the Prototype.

When designing our prototype, our team decided the sturdiest way to build our rear axle attachment was to weld the components together. However, when welding the axles from the bottom brackets together, the heat produced by the welding torch warped the steel axles, meaning the axle was no longer straight. This meant that each time we welded a component to the axle of our prototype we had to reshape the axle to ensure it was perfectly straight. Having a bent axle would not only reduce comfort, but would also cause undue stress and wear on the internal components of the bottom brackets. These stresses would include wearing down the bearings, bending the axle further, weakening the welded connections between the different bottom brackets, and stripping the bolts which connect the wheels to the axle.

Additional Design Considerations Caused Slight Modifications to the Final Design.

Once our group began to prototype the design, several issues surfaced which slightly impacted the final design.

Determining the Width and Placement of the Wheels

One of the issues our team encountered was figuring out the exact placement of the wheels. Ideally, we wanted the design to be as slim as possible to improve the aesthetics of our tricycle design. However, once we place a mock-up of our axle onto a bicycle frame, we realized that the length of the axle and the size of the wheels caused the wheels would block the pedals. Since the pedals are essential to making the bicycle move, and we could not modify the positioning of the pedals, we realized that the rear axle would either have to be placed further back so it does not impede bicycle function, or the axle would need to be widened slightly. We agreed that mounting the axle further back from the frame would potentially put too much pressure on the mounting points, causing failure due to fatigue. In order to keep the design as strong as possible, out team decided that widening the axle was the better solution. Widening the axle slightly would provide a wider wheelbase, improving stability, but would also put less stress on the points where the prototype attaches to the bicycle frame. Additionally, having our axle mounts as near as possible to where a single rear wheel would mount further makes our prototype more closely resemble a traditional bicycle.

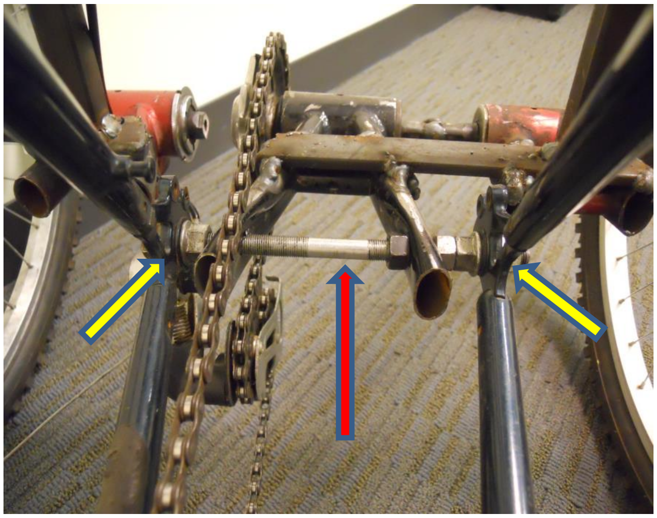


Figure 19: Shows how our prototype attaches to the rear dropouts (yellow) of a bicycle using the axle from a rear wheel hub (red).

Mounting the Wheels to Our Prototype

Mounting the wheels to the axle proved to be another design challenge. Bicycle wheels have hubs which contain their own internal components, including their own axle and bearings.

Since our axle was connected directly to the rear cassette, our drive wheel would have to be connected such that it spun as the rider pedaled. To accomplish this, on the drive side we used a rear wheel with an attached freewheel cassette to which we mounted a short piece of square stock steel. The size of the square stock was chosen to fit over the axle on the bottom brackets but also in between the teeth located on the inside of the cassette. Having the square stock fit in between the teeth meant that we could weld the square stock to the cassette so that the steel axle and cassette would rotate together, propelling the bicycle forward. The square stock connected to the wheel slides over the axle connected to the bottom bracket and attaches using two bolts. Using a square axle secure with two one quarter inch bolts means that as the rider pedals, the drive-side axle spins which in turn spins the square stock attached to the drive wheel, moving the bicycle forward. This also means that the wheel can be removed for servicing or replacing by simply undoing the bolts which hold it in place. The freewheel cassette means that the rider can stop pedaling and coast.

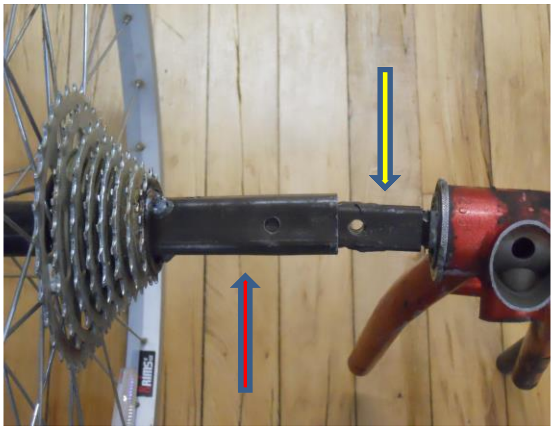


Figure 20: Depicts how the square sleeve on the bottom bracket (yellow) fits into the sleeve on the drive wheel (red).

The non-drive wheel was attached using a similar method. Since the non-drive wheel can freewheel, meaning it spins on its own according to how fast the bicycle is moving, no modifications were made to the wheel hub. Instead, we used the existing wheel axle to thread the wheel into a sleeve on the non-drive side. The sleeve was

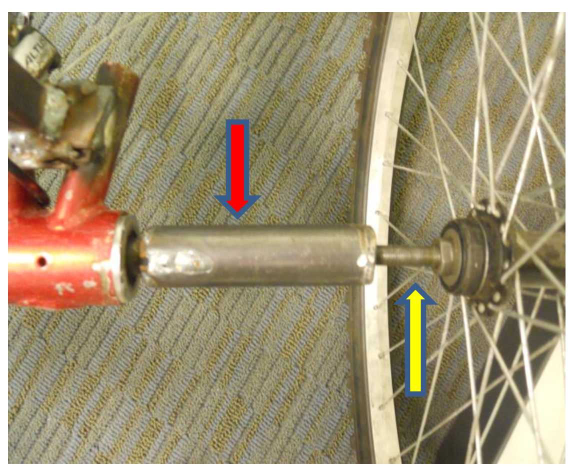


Figure 21: The non-drive wheel was threaded into a sleeve (red) using the wheel's axle (yellow).

created using two pieces of round stock steel which were welded onto the axle of the bottom bracket. Then, three axle nuts were welded together to make the threaded sleeve designed to fit the wheel's axle. This threaded sleeve was place into the round stock steel and welded into place, creating the mounting point for the non-drive wheel. The nuts did have to be ground down slightly using a bench grinder to ensure a perfect fit.

An additional consideration was that the wheels were only connected to the axle on one side, whereas on a traditional bicycle the wheels sit between the dropouts. The wheels are normally mounted between the dropouts so that the weight of the bicycle and rider is evenly distributed along the length of the wheel's hub and axle. Since our design only connects the wheel from one side, we ensured that as much of the wheel axle was threaded into this bottom bracket axle. This would ensure that the wheel's relatively small, three-eighths inch axle would not bend from the weight if the rider. We also made this decision based on our research into adaptive tricycle designs, which we found frequently use the same axle size as traditional bicycle wheels. This reassured us that the wheels' axles would be strong enough to connect from only one side without compromising strength.

Attaching Brakes to the Rear Wheels

Another issue we encountered was adapting the bicycle brakes to our design. Standard bicycles have two sets of brakes, one set connected to the front wheel and a second set connected to the back wheel. Since the rear brakes usually connect to the seat stays with a cable running down the length of the stays to the rear wheel, our design differed in the fact that we had two wheels to consider. Originally our group wanted to use disc brakes for stopping the rear wheels, however there was nowhere on the axle to mount the brake pads needed for this design. Additionally, since we want our attachment to be removable, we could not provide custom brakes because they would require changing the brake system already included on the donor bicycle. Instead, we decided to only have front brakes for the design, which will be sufficient for supervised riding.

Lengthening the Chain to Fit the Prototype

The chain connection was another piece of the bicycle that provided some difficulty. Due to the prototype's design, the wheels are located further back than on a traditional bicycle. In order to ensure the chain would be long enough to attach to the rear axle, we combined the length of two bicycle chains. We also included a rear derailleur on our prototype to act as a chain tensioner so that the gears would be functional. However, if the bicycle our prototype is attached to does not have gears, then the derailleur is not necessary. Our prototype was also designed to work with which ever derailleur is already attached to the bicycle. The only modification which would be required would be removing the existing chain and replacing it with our chain which is designed to fit the length of the attachment.

Figure 22: Our team with the finished bicycle prototype.

c. Conclusion

In the end, our team successfully designed an adaptive bicycle prototype which incorporated all of the design criteria we determined through our research and interviews. Our final prototype is entirely removable, and able to be attached to any traditional bicycle frame to transform any traditional bicycle into an adaptive slim tricycle.

VII. Additional Resources

a. Funding Future Adaptive Bicycle Projects

The fourth objective to achieve our goal was to identify appropriate sources of funding for Earn-A-Bike. As adaptive bicycles tend to be expensive, our sponsors requested we look into different methods for funding our bicycle, future adaptive bicycles, and future projects at Earn-A-Bike. Originally, we intended to use crowdfunding to fund and market our bicycle using websites such as Kickstarter and Indiegogo. However, after researching some of the limitations of crowdfunding and speaking with our sponsors, we decided grant funding was the best option for the adaptive bicycle. Our team also developed an informational brochure which contains various organizations that work with adaptive bicycles as well as grant information that Earn-A-Bike can distribute to members of the community.

The Variety of Grants Available Provide more Funding Opportunities than Crowdfunding.

A grant can be defined as a contribution bestowed by a government or other organization for specified purposes to an eligible recipient. Grants are usually conditional upon certain qualifications as to the use, maintenance of specified standards, or a proportional contribution by the grantee or other grantor(s) (Grant, 2014). We chose to look further into grants since they are more stable than crowdfunding, as crowdfunding depends on the interest of those donating and requires an extensive advertising campaign to be successful. Also, Kickstarter requires a project to reward the donors who donated to the project (Kickstarter Guidelines, 2014). Additionally, Kickstarter has an all-or-nothing approach, meaning any money raised will be returned to the donors if the goal is not reached in the given time frame (ibid). On Indiegogo, there is a 4% interest charge on money you raise if you meet your goal or 9% if you do not meet your goal

(Indiegogo FAQ, 2014). Due to these risks when using crowdfunding websites, our group decided grants would be a better option for funding our bicycle.

Grants are the best option for funding our design since no end product is required. Grants involve donors contributing sums of money to an organization whether it is in monthly installments or one initial payment. Non-profit organizations like Earn-A-Bike can apply in order to receive grants from a foundation. Also, there are terms that have to be met in order to receive funding.

Some Grant Options Target Families Seeking to Purchase Adaptive Bicycles.

When researching grants, we found some that are meant specifically for providing adaptive bicycles to families in need. However, these grants are intended for families with a member who has a disability, rather than an organization such as Earn-A-Bike. Someone seeking an adaptive bicycle for a member of their family may apply to these foundations to receive an adaptive bicycle or other necessary medical equipment, We also came across several local grants for non-profit organizations that may be interested in helping Earn-A-Bike fund future bicycles and projects at their shop.

There are a Number of Local Organizations that Earn-A-Bike could Apply to for Funding.

As student researchers, we can provide Earn-A-Bike with a list of organizations that supply grants, but cannot apply for the grants ourselves. As a resource for Earn-A-Bike, we created a spreadsheet of all the foundations we came across that could be useful for their organization. These included the foundations that provide grants to families in need of an adaptive bicycle as well as the foundations that provide grants for non-profit organizations. Some of the local organizations that provide funding to non-profit organizations include The Fletcher Foundation, Hoche-Scofield Foundation, and George F. & Sybil H. Fuller Foundation. Earn-A-

Bike will be able to use this list to find funding for future adaptive bicycles and other projects at the shop.

One section of this spreadsheet includes different organizations that families can apply to for a grant in order to receive an adaptive bicycle. Some examples include Disabled Children's Relief Fund, Wheel to Walk Foundation, and Challenged Athletes Foundation. Since adaptive bicycles are very costly, having information on different foundations which families in the Earn-A-Bike community can apply to is a great resource. Earn-A-Bike fills the need in the community by providing bicycles in an alternative way by having people volunteer at the shop rather than purchasing bicycles. Occasionally, Earn-A-Bike will sell bicycles to offset operational costs at the shop, such as rent or spare parts. One of their more popular items is children's bicycles which they sell to community members. Often members of the community can hardly afford these used bicycles, making the grants listed in our spreadsheet an even more valued resource for families who may have a member with a disability. A copy of the spread sheet is provided in Appendix D.

Since Worcester Earn-A-Bike is a non-profit organization, it is necessary to have funding for adaptive bicycles as these bicycles tend to be very expensive. For people in the community to be able to afford an adaptive bicycle, funding is an important aspect. The list of grants we left Earn-A-Bike is there for them to apply to ones they choose and to receive funding for both their organization and for families in need of an adaptive bicycle.

b. Informational Brochure on Adaptive Bicycles

An Informational Brochure will be a Resource for Community Families Seeking Information on Adaptive Bicycles.

We created an informational brochure which includes a number of resources for community families, including organizations which develop adaptive bicycles, organizations which sponsor athletic events, and various foundations which provide grants and funding for families in need of an adaptive bicycle. Since adaptive bicycles are not widely produced, the list of organizations which develop and work with these bicycles may be useful for families that desire to purchase their own bicycle or who wish to get a family member involved with an adaptive bicycling program. The list of grants can serve as a resource for families who cannot afford an adaptive bicycle. Some of these foundations provide medical equipment and services, such as wheelchairs and handicapped accessible vans, while others focus primarily on supplying adaptive bicycles to families in need.

Another section of the brochure discusses adaptive bicycles currently on the market for a range of different disabilities. We included this information in a chart containing a picture of the adaptive bicycles with its targeted disabilities listed. This chart may be useful for families to find the right bicycle for a member of their family depending on the disability. Lastly, we included a section about our adaptive bicycle design to show how Earn-A-Bike wants to give all members of the community an opportunity to earn a bicycle. An example of our brochure is provided in Appendix E.

With several different resources listed and discussed throughout the informational brochure, community members can gain insight into the various adaptive bicycles available, how to purchase one, and how Earn-A-Bike is expanding their program to include adaptive bicycles.

Chapter 5: Recommendations & Conclusions

After the completion of our project, our team has determined a number of recommendations to help Worcester Earn-A-Bike continue expanding their mission of providing bicycles to all members of the community. We believe our bicycle design is a great starting point and resource for the shop to get people with disabilities interested in cycling and become a part of the bicycling community. The following chapter offers detailed suggestions on future uses of our adaptive bicycle prototype, distribution of the informational brochure, and funding opportunities for future projects.

Continue Testing and Evaluating the Adaptive Bicycle Prototype.

As part of our project, we left Earn-A-Bike with our prototype bicycle for use at the shop. However, certain areas of the design could lead to long-term complications. Specifically, the structural integrity of our prototype should be further investigated in order to ensure the adaptation will be safe to use for teenagers and adults.

One area which our team thinks should be reevaluated is the weld joints which hold the drive-side axle together. During fabrication, the heat from the welding torch caused parts of the axle to warp, so our team recommends researching other means of joining the axles together, such as an industrial epoxy. This would prevent the axle from warping, and could potentially lead to a straighter axle.

Our team also recommends looking into various ways to incorporate rear brakes into the design. In the interest of time and simplicity, our team was unable to design an adequate braking system for the rear wheels. We recommend Earn-A-Bike continue testing different methods for braking, such as incorporating disc brakes into the axle design. Having rear brakes in addition to front brakes would make the bicycle safer by providing more stopping power.

Additionally, the bolts which connect the drive wheel to the axle should be examined for fatigue over time. Since the sleeve which the bolts pass through is made of square stock steel, the fit between them has to be perfectly snug to prevent wear on the square edges. Any movement, particularly rotational movement, could also cause wear on the bolts and the holes which they go through, weakening the connection between the drive wheel and axle leading to failure.

We recommend Earn-A-Bike consider the length of the axle. Having a longer axle presents a wider wheelbase, which would be better for balance. However, a longer axle will experience more bending stresses, and could potentially fail more easily than a shorter axle. We believe that an updated design could benefit from only using one bottom bracket instead of three. This would shorten the axle, making the tricycle slimmer than the prototyped design, making the design more aesthetically pleasing. Also, it would limit the number of welds needed to connect the axle to the bottom brackets; only the drive side of the axle would need to be welded.

Finally, since one goal of our project was to make a bicycle which was aesthetically pleasing, we recommend shortening the axle to make the design look more like a traditional bicycle. Given the time required to complete the project, we were unable to refine our design after initial testing to make the axle slimmer. We believe using one bottom bracket instead of three could be a solution to making the design slimmer. In addition to limiting the amount of welding which would need to be completed, as discussed above, only using one bottom bracket would allow Earn-A-Bike to create more of these attachments quickly. Using one bottom bracket means that for each scrap bicycle frame in stock, Earn-A-Bike could produce on rear axle attachment similar to our prototype, saving on materials and fabrication time.

Develop Multiple Iterations of the Prototype for Use at the Shop.

Once the prototype design has been refined, we recommend Earn-A-Bike builds multiple attachments so they can be used by a number of people at the shop. Since our design is intended for adults, we used 26" wheels on our prototype. However, Earn-A-Bike could ultimately produce more rear axles to attach to different bicycle sizes. For example, since the wheels are removable, they could either affix different sized wheels to our prototype or build new prototypes of the same design which incorporate smaller sized wheels.

We Recommend Earn-A-Bike Seeks Funding for Future Adaptive Bicycles from Local Foundations.

Part of our project involved researching potential sources of funding for our bicycle and future projects at Earn-A-Bike. Since Earn-A-Bike is a non-profit organization, in order for them to provide adaptive bicycles to members of the community, they need external funding, as adaptive bicycles tend to be very expensive. Also, funding is important for families in the community to be able to afford an adaptive bicycle. Together with our sponsors, our group agreed that grants are a better source of funding for this purpose because of the variety of grants available. As mentioned in Chapter Four, we are leaving Earn-A-Bike with a spreadsheet of grants they can apply to for funding as well as a resource which details the grant sources available for families wishing to purchase an adaptive bicycle.

We recommend Earn-A-Bike uses the spreadsheet of grants and apply to those most appropriate for their organization. Specifically, we recommend that Earn-A-Bike consider applying to the Fletcher Foundation, Stoddard Charitable Trust, and Wyman-Gordon Foundation. These grants primarily provide funding for Worcester based non-profit organizations which make significant impacts in the Worcester community. We believe that Earn-A-Bike's mission to provide adaptive bicycle for people with disabilities and other community members meets the criteria, and recommend they pursue application to these foundations. Additionally, there are foundations nation-wide which provide funding specifically for bicycle programs and projects. The list of grants and organizations which we recommend are included in Appendix D.

Specifically, we recommend Earn-A-Bike consider applying to the 7 Hills Foundation, People For Bikes, and the League of American Bicyclists. For example, the League of American Bicyclists provides funding specifically for women-oriented cycling programs, a niche in the Worcester community which Earn-A-Bike fills by offering weekly Women and Trans shop nights.

There are also foundations which fund or supply adaptive bicycles for families in need. While these grants are not directly applicable to Earn-A-Bike, we recommend that Earn-A-Bike use this list to inform families in the Worcester community of the various options available for obtaining adaptive bicycles. This list of family-oriented grants is also included in Appendix D.

Distribute and Publicize the Informational Brochure in the Worcester Community and to Earn-A-Bike Volunteers.

The last deliverable we are leaving with Earn-A-Bike is an informational brochure on adaptive bicycles. This brochure includes information on organizations which develop adaptive bicycles, organizations that sponsor athletic events, and various foundations which provide grants for families in need of an adaptive bicycle. We also include a table of adaptive bicycles currently on the market for a range of different disabilities, and a description of our bicycle design to serve as an example of what Earn-A-Bike could provide. We recommend Earn-A-Bike distributes these brochures at their shop and posts a copy on their website. Having these brochures readily available and publicized will help educate community families about adaptive bicycles, various resources available for purchasing them, and events for people with disabilities. Full page views of our brochure are included in Appendix E.

Earn-A-Bike Should Continue Developing Adaptive Bicycle Prototypes

Since this is the first Interactive Qualifying Project working with Earn-A-Bike, our group conducted extensive background research into adaptive bicycles and communicated with various members of the bicycling community to develop a foundation for our design. The prototype we built provided the best solution for meeting our design criteria. Specifically, the slim tricycle prototype: 1) is affordable, 2) made almost entirely of used bicycle parts, 3) uses a traditional bicycle frame, 4) includes full-sized wheels for aesthetics, 5) has handlebars which promote an upright seating position, 6) has a wide seat for added support, and 7) is adaptable to any traditional bicycle.

However, we recommend further testing, evaluating and refining of the adaptive bicycle prototype focusing on simplifying it such that Earn-A-Bike could easily build more rear axles to attach to any bicycle for someone with balance and coordination issues. Our project was an important step for Earn-A-Bike to make bicycle riding accessible to individuals with Down syndrome, autism spectrum disorder and cerebral palsy. From this starting point, Earn-A-Bike can continue its efforts to provide bicycles to people with a wider range of disabilities.

Worcester Earn-A-Bike's goal is to be able to provide bicycles to anyone in the Worcester community who wants one. Consequently, Earn-A-Bike was committed to giving people with disabilities access to bicycle riding. With several requests for adaptive bicycles, the shop managers were passionate about starting a project to help out community members in need. Our team completed extensive background research into the benefits of cycling, adaptive bicycle designs, and available adaptive bicycling programs. We interviewed individuals from the Earn-

A-Bike community, adaptive bicycle manufacturers, and athletic organizations. We conceptualized a number of designs tailored to improving balance on a bicycle and accommodating people with cognitive disabilities. Our team prototyped an adaptive bicycle design which can be attached to any traditional bicycle. Accomplishing these objectives culminated with our team providing Earn-A-Bike with an adaptive bicycle design and prototype for use at the shop, resources for funding future adaptive bicycle projects, and brochures to educate the community on adaptive bicycles. We believe that this project has successfully helped Worcester Earn-A-Bike welcome all members of the Worcester community into the world of bicycling.

References

20 Bikes, Trikes and Tandems for children with special needs. (2012, February 21). *Friendship Circle Special Needs Blog*. Retrieved January 30, 2014, from <http://www.friendshipcircle.org/blog/2012/02/21/20-bikes-trikes-and-tandems-for-children-with-special-needs/>

26" Schwinn Aluminum Comp Ladies' Mountain Bike. (n.d.). *Walmart.com*. Retrieved February 11, 2014, from <http://www.walmart.com/ip/16913450?wmlspartner=wlpa&selectedSellerId=0&adid=22222222227000883581&wl0=&wl1=g&wl2=c&wl3=41902962190&wl4=&wl5=pla&wl6=34194433390&veh=sem>

About Alyn Hospital. (n.d.). *Alyn Hospital*. Retrieved February 5, 2014, from <http://www.alyn.org/about-us/about-alyn-hospital>

About Us. (n.d.). *About AMBUCS*. Retrieved January 29, 2014, from <http://www.ambucs.org/about-us/>

About Us. (n.d.). *Recycle-A-Bicycle*. Retrieved February 5, 2014, from <http://www.recycleabicycle.org/about-us>

About. (n.d.). *Worcester Earn-A-Bike*. Retrieved February 11, 2014, from <http://worcesterearnabike.org/>

A.D.A.M Medical Encyclopedia. (2013, September 25). Multiple sclerosis. *PubMed Health*. Retrieved February 14, 2014, from <http://www.ncbi.nlm.nih.gov/pubmedhealth/PMH0001747/>

AmTryke. (n.d.). *AmTryke*. Retrieved January 29, 2014, from <http://www.ambucs.org/amtryke/>

Åström, K., Klein, R., & Lennartsson, A. (2005). Bicycle Dynamics and Control: Adapted Bicycles for Education and Research. *IEEE Control Systems Magazine*, *August*, 26-47.

Benjamin, B. E. (2004). Cycling and Your Health. *Massage Therapy Journal*. Retrieved April 13, 2014, from <http://www.bycycleinc.com/pages/article_MTJ.html>

Berkeley's Blue Team (2011). *Ghostrider*. University of Berkeley. <http://journalism.berkeley.edu/projects/mm/zack/index.html>

Bicycles and Tricycles, Special Needs. (n.d.). *adaptivemall.com*. Retrieved January 30, 2014, from <http://www.adaptivemall.com/specneedtric.html>

Bicycle Wheel Gyroscope. (n.d.). *Science Supplies & Curriculum*. Retrieved April 15, 2014, from http://www.carolina.com/catalog/detail.jsp?prodId=752198&s_cid=ppc_gl_products&gclid=CNzIrKa94L0CFUtk7Aod8XwAzg

Bike camp for persons with disabilities still has openings. (2012, May 11). *McClatchy - Tribune Business News*. Retrieved from <http://ezproxy.wpi.edu/login?url=http://search.proquest.com/docview/1012177511?accountid=29120>

"Bikes and Ride Ons." *Flaghouse Physical Education Equipment - Special Needs - CATCH – Snoezelen*. N.p., n.d. Web. 3 Feb. 2014. <http://www.flaghouse.com/index.asp>

Blue, Elly. (2011, Jul 18). The Bike Factor: Disability and the ability to ride a bicycle. *Grist*. Retrieved January 27, 2014, from <http://grist.org/biking/2011-07-18-the-bike-factor-disability-and-the-ability-to-ride-a-bicycle/>

Bryant, B. (n.d.). What's The Deal With Crank Forwards?. *bike123*. Retrieved April 13, 2014, from http://www.bike123.com/crank%20forward.htm

Cameron, L. & Murphy, J. (2002, Sep 13). Enabling Young People with a Learning Disability to Make Choices at a Time of Transition. *British Journal of Learning Disabilities*, 30(3), 105-112. DOI: 10.1046/j.1468-3156.2002.00165.x

CareNotes. Truven Health Anaytics Inc. (2013). Fetal Alcohol Syndrome. *Health Reference Center Academic.* Retrieved February 14, 2014, from <http://go.galegroup.com/ps/i.do?id=GALE|A347294415&v=2.1&u=mlin_c_worpoly&it=r&p=HRCA&sw=w>

Clark, A. (2010, July 1). Muscular Dystrophy. *KidsHealth – the Web's most visited site about children's health.* Retrieved February 14, 2014, from <http://kidshealth.org/teen/diseases_conditions/bones/muscular_dystrophy.html>

Cycling. (n.d.). Special Olympics. Retrieved February 10, 2014, from <http://digitalguides.specialolympics.org/cycling/?#/18>

Disability Cycles | Buy Bikes Online | Get Cycling Online Cycle Shop. (n.d.).*Disability Cycles | Buy Bike Online | Get Cycling Online Cycle Shop*. Retrieved January 30, 2014, from <http://www.getcycling.org.uk/browse.php?id=12>

Doria, A., Tognazzo, M., Cusimano, G., Bulsink, V., Cooke, A., Koopman, B. (2013) Identification of the mechanical properties of bicycle tyres for modelling of bicycle dynamics. *Vehicle System Dynamics*. 51:3, 405–420. DOI: 10.1080/00423114.2012.754048

Dressel, A., Rahman, A. (2012). Measuring sideslip and camber characteristics of bicycle tyres. *Vehicle System Dyn*amics. 50:8, 1365–1378. DOI: 10.1080/00423114.2011.615408

Cycling. (n.d.). *Special Olympics*. Retrieved January 29, 2014, from <http://www.specialolympics.org/cycling.aspx>

Fetal Alcohol Spectrum Disorders: MedlinePlus. (n.d.). *U.S. National Library of Medicine*. Retrieved February 13, 2014, from <http://www.nlm.nih.gov/medlineplus/fetalalcoholspectrumdisorders.html>

Fitzroy, M. (2011, Jun 16). Kids with disabilities learn how to ride bikes at special camp at fletcher high. *McClatchy - Tribune Business News*. Retrieved from <http://ezproxy.wpi.edu/login?url=http://search.proquest.com/docview/872069133?accountid=29120>

Fix, E. (n.d.) Tips to Finding the Right Bike. *Arthritis Foundation*. Retrieved February 13, 2014, from <http://www.arthritistoday.org/what-you-can-do/staying-active/gadgets-and-gear/finding-the-right-bike.php>

"Freedom Concepts Discovery Mini Tricycle." *Special Needs Strollers, Toys and Adaptive Equipment*. N.p., n.d. Web. 3 Feb. 2014. <http://www.especialneeds.com/>

"Funds raised to help buy bikes for disabled". *Grimsby evening telegraph*, p. 5.

Gallery: Recycle-A-Bicycle Teaches NYC Kids How to Fix Bicycles (n.d.). *Inhabitat New York City RecycleABicycle Comments*. Retrieved February 5, 2014, from <http://inhabitat.com/nyc/recycle-a-bicycle-teaches-nyc-kids-how-to-fix-bikes-help-the-environment/recycle-a-bicycle5/>

Giving kids the chance to Dream more - and live more. (n.d.). *Saint Louis BikeWorks*. Retrieved February 5, 2014, from < http://www.bworks.org/bikeworks/earn-a-bike/>

"Go Glider 16-Inch Balance Training Bike (Large)." *Amazon.com: Go Glider 16-Inch Balance Bike: Sports & Outdoors*. N.p., n.d. Web. 5 Feb. 2014. <http://www.amazon.com>

Grant. (2014). *BusinessDictionary.com*. Retrieved April 14, 2014, from <http://www.businessdictionary.com/definition/grant.html>

Grenoble, R. (2013, September 24). Man Born Without Arms Rides Bike Built By Custom Manufacturer (VIDEO). *The Huffington Post*. Retrieved January 30, 2014, from <http://www.huffingtonpost.com/2013/09/24/michael-trimble-man-no-arms-rides-bike_n_3982966.html>

Hamalainen, K. (2012). A Bicycle Revolution: People Across the U.S. are Riding Bikes More--Improving Their Health and Helping the Planet. *Scholastic, Inc.*

Handcycling. (n.d.). *Handcycling*. Retrieved January 30, 2014, from <http://www.handcycleracing.com/Handcycles.html>

"Hand/Foot Cycles." *Welcome to AmTryke LLC*. N.p., n.d. Web. 3 Feb. 2014. <http://www.amtrykestore.org/>

Herlihy, D.V. (2004). *Bicycle: The History*. Yale University Press, New Haven, CT.

Hibbet, B. (n.d.). Amputee Bicycling: Great for Body and Mind. Oandp.com. Retrieved February 14, 2014, from <http://www.oandp.com/articles/2005-01_10.asp>

Holmes, K. E. (2013, Aug 09). Two-wheeled self-confidence: Special bikes for special kids. *McClatchy - Tribune Business News*. Retrieved from <http://ezproxy.wpi.edu/login?url=http://search.proquest.com/docview/1418727892?accountid=29120>

Hornyak, J. E., Lloyd, M., Tiernan, C., & Ulrich, D. A. (2008). Course 449: Pediatrics: The benefits of Learning How to Ride a Two-Wheel Bicycle for Children with Down Syndrome. *Archives of Physical Medicine and Rehabilitation, 89(11), e5-e5.* DOI:10.1016/j.apmr.2008.09.004

Indiegogo FAQ. (2014). *Indiegogo*. Retrieved April 14, 2014, from <https://www.indiegogo.com/indiegogo-faq>

Kaplan, S. H., & Fineman, A. M. (2010). *Design of an Active-Assistance Balancing Mechanism for a Bicycle*. Undergraduate Major Qualifying Project. Worcester Polytechnic Institute.

Klein, R.E., Lieberman, L., DiRocco, P., McHugh, E. (2002). Adapted bikes deliver new independence. *Exceptional Parent*. 32:10, 64–66.

Kickstarter Guidelines. (2014). *Kickstarter*. Retrieved April 14, 2014, from <https://www.kickstarter.com/help/guidelines>

Kickstarter Vs IndieGoGo: Choosing Your Crowdfunding Platform. (n.d.). *Crowdfunding Dojo*. Retrieved February 23, 2014, from <http://crowdfundingdojo.com/articles/kickstarter-vs-indiegogo-choosing-your-crowdfunding-platform>

Kooijman, J. D. G., Meijaard, J. P., Papadopoulos, J. M., Ruina, A, Schwab, A. L. (2011) Bicycle Can Be Self-Stable Without Gyroscopic or Caster Effects. *Science*. DOI: 10.1126/science.1201959.

Kulhavy, J. A. (2002, Mar 26). *U.S. Patent No. US6360838 B1.* Washington, DC: U.S. Patent and Trademark Office.

Kraft, T. E. (2005, March). The Bicycle: A Great Vehicle for Learning. *Ann Arbor: Prakken Publications.*

Krauter, A.I. (1973, Sep). Steady-state cornering of two-wheeled vehicles. *Journal of Applied Mechanics.* 819–821.

Learn How to Raise Money for an Idea. (n.d.). *Indieigogo*. Retrieved February 20, 2014, from <http://www.indiegogo.com/learn-how-to-raise-money-for-a-campaign>

Lewak, Doree. "Pimp their ride." *Pimp Their Ride*. New York Post, 8 Nov. 2011. Web. 28 Feb. 2014. <http://nypost.com/2011/11/08/pimp-their-ride/>.

Lurie, D. K. (2012). *Stability of Three-Wheeled and Two Wheel Bicycles*. Undergraduate Major Qualifying Project. Worcester Polytechnic Institute.

MacDonald, M., Esposito, P., Hauck, J., Jeong, I., Hornyak, J., Argento, A., & Ulrich, D. (2012). Bicycle Training for Youth with Down Syndrome and Autism Spectrum Disorders. *Focus on Autism and Other Developmental Disabilities, 27*(1), 12-21. DOI:10.1177/1088357611428333.

MacDonald, M., Jaszewski, C., Esposito, P., & Ulrich, D. (2011). The Effect of Learning to Ride a Two-Wheel Bicycle on the Social Development of Children with Autism Spectrum Disorder. *Macomb: The McDonough Democrat.*

Mann, M. (2013, September 20). "I Am a Brand": Kickstarter Versus Indiegogo for Filmmakers. *Blouin Artinfo*. Retrieved February 23, 2014, from <http://www.blouinartinfo.com/news/story/961304/i-am-a-brand-kickstarter-versus-indiegogo-for-filmmakers>

Mathias, M. *(2011).* Riding Bikes: A Pastime for Every Child. *EP Global Communications, Inc.*

Meijaard, J.P., Papadopoulos, J.M., Ruina, A., Schwab, A.L. (2007). Linearized dynamics equations for the balance and steer of a bicycle: A benchmark and review. *Proceedings of the Royal Society*. A 463, 1955–1982. DOI: 10.1098/rspa.2007.1857

Mental Illnesses. (n.d.). *NAMI: National Alliance on Mental Illness.* Retrieved March 1, 2014, from <http://www.nami.org/Template.cfm?Section=By_Illness>

Metals Depot - America's Metal Superstore!. (n.d.). *Metals Depot®*. Retrieved April 15, 2014, from <http://www.metalsdepot.com/>

Mission. (n.d.). Wounded Warrior Project. Retrieved February 15, 2014, from <https://www.woundedwarriorproject.org/mission.aspx>

Moore, J. K., Kooijman, J.D.G.,Schwab A.L. (2009). Some Observations on Human Control of a Bicycle.*Proceedings of the ASME 2009 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC/CIE 2009).*

Murnen, H., Niles, A., Sigworth, N., Sperling, D. (2009, Oct 06). *U.S. Patent No. US7,597,337 B2.* Washington, DC: U.S. Patent and Trademark Office.

Murray, C. J. (1993). Bike for handicapped reaches market. *Design News*, *49*(11), 34.

New 26" 7 SPEED beach cruiser bicycle bike forward crank CA520. (n.d.). *eBay*. Retrieved April 15, 2014, from <http://www.ebay.com/itm/like/281008902021?lpid=82>

New Metals. (n.d.). *Sullivan Metals*. Retrieved April 14, 2014, from <http://www.sullivanmetals.com/>

News. (2014, January 26). Children with special needs in Lufkin get therapeutic bikes. ABC local. Retrieved January 29, 2014, from <http://abclocal.go.com/ktrk/story?section=news/state&id=9407749>

NINDS Traumatic Brain Injury Information Page. (n.d.). *National Institute of Neurological Disorders and Stroke*. Retrieved February 13, 2014, from <http://www.ninds.nih.gov/disorders/tbi/tbi.htm>

“One dream, born to build even more dreams.” (n.d.). *Saint Louis BikeWorks*. Retrieved February 5, 2014, from <http://www.bworks.org/bikeworks/our-mission-and-history/>

Ostler, S. (2008, November 27). Berkeley shop adapts bikes for any disability.*SFGate*. Retrieved January 30, 2014, from <http://www.sfgate.com/sports/article/Berkeley-shop-adapts-bikes-for-any-disability-3260310.php>

Papavasiliou, A. S. (2009, Sep). Management of Motor Problems in Cerebral Palsy: A Critical Update for the Clinician. *European Journal of Pediatric Neurology*, 13(5), 387-396.

Patrin, R. A. (1987, Dec 15). *U.S. Patent No. US4,712,806 A.* Washington, DC: U.S. Patent and Trademark Office.

Parrish, T. N. (2012, Nov 05). My bike rolls out customized bikes for western pennsylvania youths with disabilities. *McClatchy - Tribune Business News*. Retrieved from <http://ezproxy.wpi.edu/login?url=http://search.proquest.com/docview/1128562715?accountid=29120>

Prive, T. (27 Nov 2012). What Is Crowdfunding And How Does It Benefit The Economy. *Forbes*. Retrieved February 20, 2014, from <http://www.forbes.com/sites/tanyaprive/2012/11/27/what-is-crowdfunding-and-how-does-it-benefit-the-economy/>

"Power Pumper JR." *Power Pumper RSS*. N.p., n.d. Web. 30 Jan. 2014. <http://www.powerpumper.com/>

"Product Categories"."*Trailmate*. N.p., n.d. Web. 1 Feb. 2014. <http://www.trailmate.com/product.cfm?proID=38>

Programs. (n.d.). *Wounded Warrior Project*. Retrieved February 15, 2014, from <http://www.woundedwarriorproject.org/programs.aspx>

Recumbent Bikes & Trikes for Health, Fitness, Exercise, PT, OT, Therapy, Handicapped, Rehab, Cardio Rehab & Veterans. (n.d.). *Bicycle Man, LLC*. Retrieved January 29, 2014, from <http://www.bicycleman.com/recumbents/recumbent-health-and-fitness.htm>

"Rifton Adaptive Tricycles." *Rifton*. N.p., n.d. Web. 31 Jan. 2014. <http://www.rifton.com/products/special-needs-tricycles/adaptive-tricycles>

Schleien, S.J., & Mactavish, J.B. (2001, Jan 14). Re-injecting Spontaneity and Balance in a Family life: Parents' Perspectives on Recreation in Families that Include Children with Developmental Disability. *Journal of Intellectual Disability Research.*

Schwab, A. L., Meijaard J. P. (2013). A review on bicycle dynamics and rider control. *Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility*. 51:7. 1059-1090. DOI: 10.1080/00423114.2013.793365

Sharp, R.S. (2008). On the stability and control of the bicycle. *Applied Mechanics Review.* 61:060803. 1–24. DOI: http://dx.doi.org/10.1115/1.2983014

Soldier Ride. (n.d.). *Wounded Warrior Project*. Retrieved February 15, 2014, from <https://www.woundedwarriorproject.org/programs/soldier-ride.aspx>

"Special bikes for disabled". *Derby Evening Telegraph*, p. 6.

Special Needs Tricycles & Bicycles. (n.d.). *ESpecial Needs*. Retrieved February 5, 2014, from <http://www.especialneeds.com/adaptive-equipment-special-needs-tricycles-bicycles.html>

Spina Bifida – Topic Overview. (2011, March 21). *WebMD*. Retrieved February 13, 2014, from <http://www.webmd.com/parenting/baby/tc/spina-bifida-topic-overview>

Shrestha, S., Lofgren, J. B., Bayreuther, J. L. (2003). *Building a Cyclist's Comfort Guide*. Unpublished Interactive Qualifying Project. Worcester Polytechnic Institute.

Sunlite HD Adjustable Training Wheels 20-26". (n.d.). *BicycleBuys*. Retrieved April 16, 2014, from <http://www.bicyclebuys.com/>

Swiech, Paul. "AMBUCS Volunteer Builds Bikes for Disabled." *McClatchy - Tribune Business News*Jul 05 2013. *ProQuest.* Web. 27 Jan. 2014 <http://search.proquest.com/docview/1394870013>

The Annual Bike Ride for the Children of ALYN Hospital. (n.d.). *Wheels of Love (WOL)*. Retrieved February 5, 2014, from <http://www.alynride.org/?CategoryID=185>

"The Go Anywhere Wheelchair Bicycle Tandem: The Duet." *Frank Mobility Systems Inc*. N.p., n.d. Web. 9 Feb. 2014. <http://www.frankmobility.com/duet.php>

Ulrich, D. A., Burghardt, A. R., Lloyd, M., Tiernan, C., & Hornyak, J. E. (2011). Physical Activity Benefits of Learning to Ride a Two-Wheel Bicycle for Children with Down Syndrome: A randomized trial. *Physical Therapy, 91*(10), 1463-1477. DOI:10.2522/ptj.20110061

Vanbergeijk, E. O. (2013). Bike Riding: For Family Fun and Exercise. *EP Global Communications, Inc*.

What is Fibromyalgia? (n.d.) *Arthritis Foundation*. Retrieved February 13, 2014, from <www.arthritistoday.org/about-arthritis/types-of-arthritis/fibromyalgia/what-you-need-to-know/what-is-fibromyalgia.php>

What is Osteoarthritis? (n.d.) *Arthritis Foundation*. Retrieved February 13, 2014, from <http://www.arthritistoday.org/about-arthritis/types-of-arthritis/osteoarthritis/what-you-need-to-know/osteoarthritis-is.php>

What is Rheumatoid Arthritis? (n.d.). *Arthritis Foundation.* Retrieved February 13, 2014, from <http://www.arthritistoday.org/about-arthritis/types-of-arthritis/rheumatoid-arthritis/what-you-need-to-know/what-is-ra.php>

Wisconsin Chapter. (n.d.). myTEAM TRIUMPH. Retrieved February 10, 2014, from <http://myteamtriumph-wi.org/about/>

Wortham, Jenna (2012). Success of Crowdfunding Puts Pressure on Entrepreneurs. *New York Times, September, 17*.

Appendix A: Interview Questions

The following introduction was included as a preamble to each set of interview questions:

Thank you for your prompt response to our inquiry about adaptive bicycles and agreeing to participate. The information you provide may be included in our final report to be delivered to our sponsor, Worcester Earn-A-Bike, as well as made publicly available through Worcester Polytechnic Institute's project library. Your participation in this interview is completely voluntary and you may withdraw your participation or any information you submit at any time. If you wish for your identity or the identity of your organization to remain anonymous please let us know.

Below we have provided some questions we are hoping will help us determine what modifications can be made to a bicycle to make it usable by people with Downs syndrome, cerebral palsy or autism spectrum disorder.

This is a collaborative project between Worcester Earn-A-Bike and WPI, and your participation is greatly appreciated. If interested, a copy of our results can be provided at the conclusion of the project.

Interview Questions for AmTryke & Bicycle Man Employees

1. While working at AmTryke and Bicycle man, which age groups most often seek adaptive bicycles?
2. Which disabilities do you provide the most bicycles for?
3. Does the type of bicycle that you recommend vary by disability?
4. What types of bicycles are most commonly requested by those with disabilities that your companies serve?
5. What seems to be the hardest aspect of riding a bicycle for the population to which you most frequently sell bicycles?
6. Do you have customers with either Down syndrome, autism, or cerebral palsy?
    a. If so, what type of bicycle do you suggest for them?
    b. Why?
7. When developing an adaptive bicycle, do your companies modify commercially available bicycles, or start from scratch and build a bicycle from the ground up?
8. Do you have any recommendations for additional bicycle modifications that might make a bicycle easier for a disabled rider to use?
9. Do you host any fundraising, awareness, or community service events at Bicycle Man or AmTryke?
10. Our project requires building a two-wheeled bicycle with balance aids, if possible, rather than using a tricycle design. Do you have any experience building or working with similar bicycles?
11. Do you know of any successful bicycle designs which have used gyroscopes?

12. What makes crank forward bicycles better than an upright bicycle for individuals with Down syndrome, autism, or similar disabilities?
13. Can you suggest any other individuals, organizations, or companies that we might speak with?
14. Lastly, would it be alright if we contacted you with additional questions?

Interview Questions for Employee of AMBUCS

1. During your time at AMBUCS, which age groups have you noticed most often seek adaptive bicycles?
2. Which disabilities do you provide the most bicycles for?
3. What types of bicycles are most commonly requested by those with disabilities that your companies serve?
4. Does the type of bicycle that you recommend vary by disability? If so, why?
5. What seems to be the hardest aspect of riding a bicycle for the population to which you most frequently sell bicycles?
6. Do you have customers with either Down syndrome, autism, or cerebral palsy?
    a. If so, what type of bicycle do you suggest for them?
    b. Why?
    c. What are additional bicycle options that you might suggest?
7. When developing an adaptive bicycle, such as the AmTryke, is it more feasible to modify commercially available bicycles, or start from scratch and build a bicycle from the ground up?
8. During the course of our research, we found information regarding the use of gyroscopes to stabilize bicycles. Do you know of any successful designs?
9. Would you suggest using gyroscopes as a viable alternative to a tricycle when designing an adaptive bicycle?
10. Are there any other modifications you would suggest that would be more feasible or cost-effective?
11. Can you suggest any other individuals, organizations, or companies that we might speak with?
12. Lastly, would it be alright if we contacted you with additional questions?

Interview Questions for Special Olympics Bicycling Coaches and Athletes

Coaches:

1. What does being a cycling coach entail at Special Olympics?
2. Which age groups do you mostly work with?
    a. Our project is focusing on adults, do you have any participants that are older?
    b. What bikes do they ride?
    c. Do you have any recommendations for modifications for these bikes?
3. Which disabilities do people you work with at Special Olympics most commonly have?
4. What types of bicycles are most commonly used by those with disabilities?

5. Does the type of bicycle that you use at Special Olympics vary by disability?
    a. Why?
6. What seems to be the hardest aspect of riding a bicycle for most people in your program?
7. Do you have participants with Down syndrome, autism, or cerebral palsy?
    a. If so, what type of bicycle do you suggest they ride?
    b. Why?
    c. Are there additional bicycle options that you might suggest?
8. Do you supply bicycles or do participants bring their own?
    a. If you do supply bicycles, does Special Olympics typically modify available bicycles or buy them already made?
    b. Do you use any local bike shops to maintain or purchase adaptive bicycles?
9. Do you have any recommendations for additional bicycle modifications that might make a bicycle easier for a person with physical or cognitive disabilities to use?

Part of our project requires that we develop a funding and marketing recommendation for our sponsor, Worcester Earn-A-Bike, so that they will have the means of manufacturing the bicycle we design since Earn-A-Bike is a non-profit organization.

10. Do you host any fundraising, awareness, or community service events at Special Olympics?
    a. By what means do you fundraise?
11. What events does the cycling team at Special Olympics participate in?
12. Do you have any pictures of the bicycles you use? Can you send them to us?
13. Does Special Olympics have any events coming up that we could attend to see these bicycles being put to use?
14. Earn A Bike is trying to put together a list of useful contacts/ resources that may be listed on a brochure or their website. Who do you suggest we contact?
15. Can you suggest any other individuals, organizations, or companies that we might speak with to gain additional insight?
16. Lastly, would it be alright if we contacted you with additional questions?

Athletes:
1. What do you like to do for fun? Any hobbies? Sports?
2. Did you enjoy riding a bicycle? Would you mind telling us a bit about your experience?
3. Was there anything you didn't like about riding a bicycle?
    a. c. What kind(s) of bicycle? Was it two wheeled, etc?
    b. d. What is the most difficult thing about riding your bicycle?
4. Would you be interested in a two-wheeled bicycle that could balance itself?
5. Have you been involved in any biking organizations? Have you ever heard about Worcester Earn-A-Bike?
    a. Would you be interested in volunteering there?
6. Have you ever worked on a bike?
    a. Have you, members of your family or friends ever made any modifications to *your* bicycle?

Interview Questions for My Team Triumph

1. While working at My Team Triumph, which age groups have you noticed most often participate as a Captain?
2. What are the most commonly represented physical and/ or intellectual disabilities of My Team Triumph event participants?
3. Undoubtedly there are numerous social benefits to My Team Triumph participants. Could you please describe the array of social benefits for people with disabilities competing in My Team Triumph?
4. What physical benefits are there for people with disabilities competing in My Team Triumph?
5. Can you describe the bicycle/trailer that the Angels use to push the Captains?
    a. Are there different modifications depending on the Captain's physical or cognitive disability?
6. Are there any people with disabilities that ride their own bike in your events?
7. Does My Team Triumph provide bicycles, or do participants supply their own?
8. What seems to be the hardest aspect of riding a bicycle for most people with disabilities?

Part of our project requires that we develop a funding and marketing recommendation for our sponsor, Worcester Earn-A-Bike, so that they will have the means of manufacturing the bicycle we design since Earn-A-Bike is a non-profit organization.

9. Does your organization receive outside funding, such as private grants; local, state or federal funding; or crowdfunding?
10. Can you suggest any other individuals, organizations, or companies that we might speak with?
11. Lastly, would it be alright if we contacted you with additional questions?

Interview Questions for iCan Shine

1. We were really interested in your program and how you teach the children to ride. Can you describe your methods of teaching in detail?
2. We understand that you attach rollers to bicycles, if the kids do not progress in the allotted time can they keep the rollers so they can continue to practice?
3. What is your success rate within your program?
4. What are the most challenging issues that children face in the program?
5. What is the most rewarding part of your program?
6. Do you help kids with Down syndrome, autism, or cerebral palsy learn how to ride bicycles?
7. Do you have any experience with other adaptive bicycles?
8. Do you have any recommendations for bicycle modifications that might make it easier for people with disabilities to ride?
9. How is your program funded?
10. Does your organization receive any grants to help with funding?

11. Can you recommend any organizations or programs that will help us in our research?
12. For part of our project we are making a brochure of resources for families with children with special needs. Would you mind if we listed your organization as a potential resource for these families?

Interview Questions for Physical Therapists at Special Needs Schools

1. What does your work at the Boston College Campus School entail?
2. Do you have students there that ride adaptive bicycles?
3. Which disabilities are your students most commonly diagnosed with?
4. Which age groups do you mostly work with?
5. What types of bicycles are most commonly used by those with disabilities?
6. What seems to be the hardest aspect(s) of riding a bicycle for most people in your program?
7. Do you have participants with Down syndrome, autism, or cerebral palsy?
8. Does the Boston College Campus School typically modify available bicycles or buy commercially available bicycles?
12. Do you have any recommendations for additional bicycle modifications that might make a bicycle easier for a person with physical or cognitive disabilities to use?
13. Do you have any pictures of the bicycles you use? Can you send them to us?

Part of our project requires that we develop a funding and marketing recommendation for our sponsor, Worcester Earn-A-Bike, so that they will have the means of manufacturing the bicycle we design since Earn-A-Bike is a non-profit organization.

14. Does your school receive any funding or grants to obtain these bicycles?
15. Earn A Bike is trying to put together a list of useful contacts/ resources that may be listed on a brochure or their website. Can you suggest any other individuals, organizations, or companies that we might speak with to gain additional insight?
16. Lastly, would it be alright if we contacted you with additional questions?

Interview Questions for Member of Earn-A-Bike whose Child has a Disability

1. What do you like to do for fun? Any hobbies? Sports?
2. Have you ever Ridden a bicycle?
    a. If so:
        ii. Did you enjoy riding a bicycle? Would you mind telling us a bit about your experience?
        iii. Was there anything you didn’t like about riding a bicycle?
        iv. What kind(s) of bicycle? Was it two wheeled, etc?
        v. What is the most difficult thing about riding your bicycle?
    b. If not:
        i. Why not?

        ii. What kinds of bikes would you be interested in?

3. Would you be interested in a two-wheeled bicycle that could balance itself?
4. Have you been involved in any biking organizations?
    a. We understand that you're friends with Jon Sher, have you ever volunteered or participated in shop hours?
        i. If so: How was it?
5. Have you ever worked on a bike?
    a. Have you, members of your family or friends ever made any modifications to *your* bicycle?
    b. What additional modifications would you make if you could? What would you change?

Interview Questions for Family of Teenager with Disability

1. We understand your daughter has ridden a bicycle in the past. What type of bicycle did she ride?
2. What was her experience like when riding a bicycle?
    a. Did she enjoy riding a bicycle?
    b. Was there anything she didn't like about riding a bicycle?
    c. What is the most difficult thing about riding bicycle for her?
3. Does she still ride bicycles? If not, why?
4. What changes would she like to be made to a bicycle to make it easier to ride/ aesthetically pleasing?
5. Would she be interested in a two-wheeled bicycle that could balance itself?
6. Have you been involved in any biking organizations?
    a. Have you ever heard of Earn-A-Bike or participated in volunteer events at the shop?
7. Have you ever worked on a bike?
    a. Have you, members of your family or friends ever made any modifications to her bicycle?
    b. What additional modifications would you make if you could? What would you change?

Interview Questions for Hand Cyclist

1. How did you get into biking?
2. Where did you get your bicycle?
3. Besides Earn-A-Bike, do you go to any other shops to work on your bike, or do you do most of the work yourself?
4. How well does your bike function for you?
5. Would you be interested in any changes? If so, what?
6. Additional recommendations?
7. Can you recommend any resources for people looking for adaptive bicycles, such as financial resources, repair shops, or training programs?

Appendix B: Materials for Bicycle

Note: Parentheses indicates quantity, measurements given as L x D (length x diameter), L x W (length x width), or L x W x T (length x width x thickness). "The Metal Shop" is shop space utilized by one of our sponsors.

Quantity	Dimensions	Description	Acquired From	Price
1	Bicycle sized for intended rider	Bicycle with all components attached	Earn-A-Bike	N/A
3	N/A	Stripped steel bicycle frames	Earn-A-Bike	N/A
2	26 in	Rear wheels (one with an attached cassette)	Earn-A-Bike	N/A
2	26 in	Mountain bike tires	Earn-A-Bike	N/A
1	1 ¾ x ½ in (L x W)	Solid Steel square stock	The Metal Shop	N/A
1	1 x ½ in (L x W)	Solid steel square stock	The Metal Shop	N/A
1	3 ¼ x ¾ in (L x W)	Hollow Steel Square Stock	The Metal Shop	N/A
1	3 ⅝ x 1 in (L x W)	Hollow Steel Square Stock	The Metal Shop	N/A
1	2 ½ x ⅞ in (L x D)	Hollow Steel Round Stock	The Metal Shop	N/A
1	3 ⅞ x 1 1/16 in (L x D)	Hollow Steel Round Stock	The Metal Shop	N/A
2	4 x ¾ in (L x W)	Hollow Steel Square Stock	The Metal Shop	N/A
1	10 ½ x ¾ in (L x W)	Hollow Steel Square Stock	The Metal Shop	N/A
2	9 ¾ x ½ in (L x W)	Hollow Steel Square Stock	The Metal Shop	N/A
1	15 x ½ in (L x W)	Hollow Steel Square Stock	The Metal Shop	N/A
1	7 ¾ x 1 x ¼ in (L x W x T)	Steel Bar Stock	The Metal Shop	N/A
1	2 ⅝ x 1 x ¼ in (L x W x T)	Steel Bar Stock	The Metal Shop	N/A
1	1 ½ x ⅜ in (L x D)	M8 Fine Thread Steel Bolt	Barrows Hardware	$1.00

2	1 ½ x ¼ in (L x D)	Steel bolts with nuts and lock washers	Barrows Hardware	$1.25
2	N/A	Bolts with washers used for rear brake mounts	Earn-A-Bike	N/A
1	¼ in	Steel bolt with nut	Earn-A-Bike	N/A
9	⅜ in	Axle Hex Nuts	Earn-A-Bike	N/A
1	⅜ in	Rear bicycle wheel axle	Earn-A-Bike	N/A
1	Custom length	Bicycle chain	Earn-A-Bike	N/A

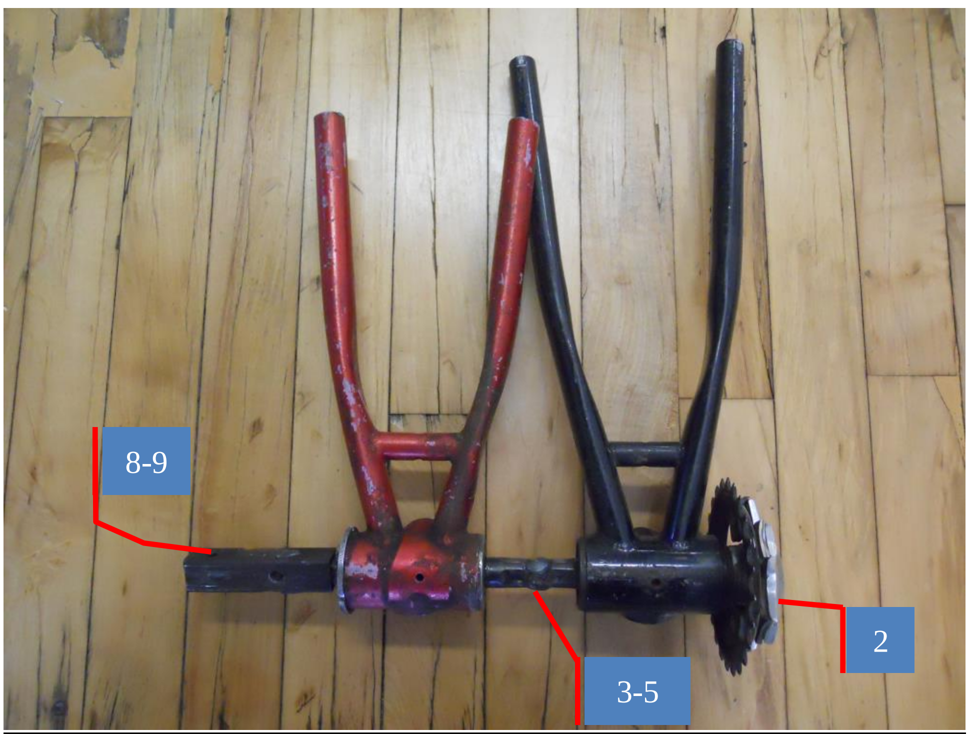
Appendix C: Instructions for Prototyping

*Note: Starting with a bicycle containing all attached parts, remove rear wheel, rear brakes, and chain. From there, follow these steps with the materials list we provided.

<u>From Scrap Bicycle Frames</u>

1) Cut off 3 bottom brackets from scrap bicycle frames leaving chain stays attached. One bracket should contain a crank for the drive side. The crank axles should be female threaded.

<u>Drive Side of Prototype Axle</u>



2) Angle grind two of the three gears off of the crank, leaving the smallest gear attached.

3) Cut 3/8 fine threaded bolt into 7/8 in. threaded section.

4) Thread bolt into axles of two bottom brackets (one bracket must be the one containing the sprocket). This will align the axles for welding.

5) Weld the two axles together.

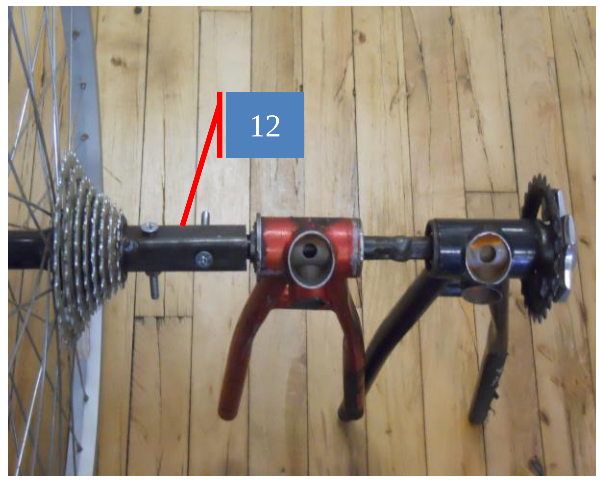
6) Cut one piece of solid steel square stock to 1 ¾ x ½ in. (L x W).

7) Cut two pieces of hollow steel square stock to 3 ¼ x ¾ in. and 3 ⅝ x 1 in. (L x W).

8) Weld 1 ¾ x ½ in. solid square stock to the axle of the drive side of the bottom bracket on the opposite end from the crank.

9) Weld 3 ¼ x ¾ in. hollow square stock to axle of drive side of bottom bracket- enclosing the solid square stock.

10) Slide 3 ⅝ x 1 in. hollow square stock over two other square stock and drill two ¼ inch holes through each square stock.

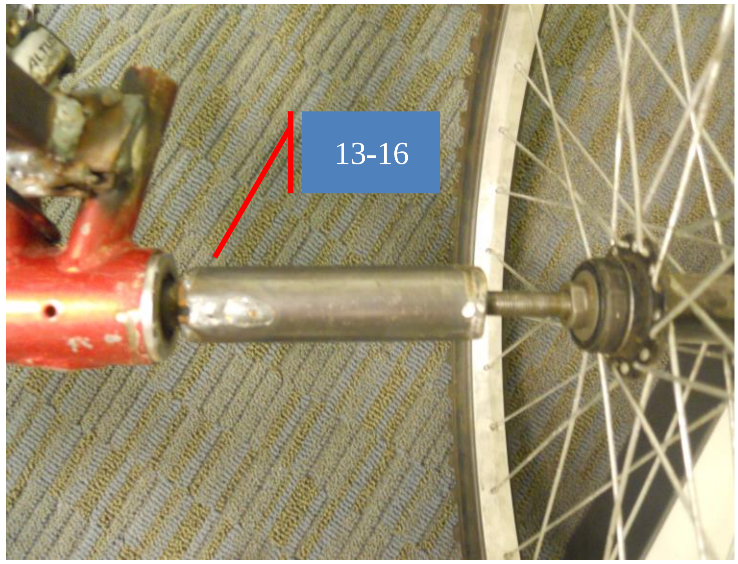


11) Remove 3 ⅝ x 1 in. hollow square stock and weld it to the cassette on the drive wheel.

12) By sliding the wheel with the welded 3 ⅝ x 1 in. stock back over the axle, place the 1½ x ¼ in. bolts through the ¼ in. drilled holes and lock on with nuts.

* This step secures the drive wheel to the axle

Non-Drive Side



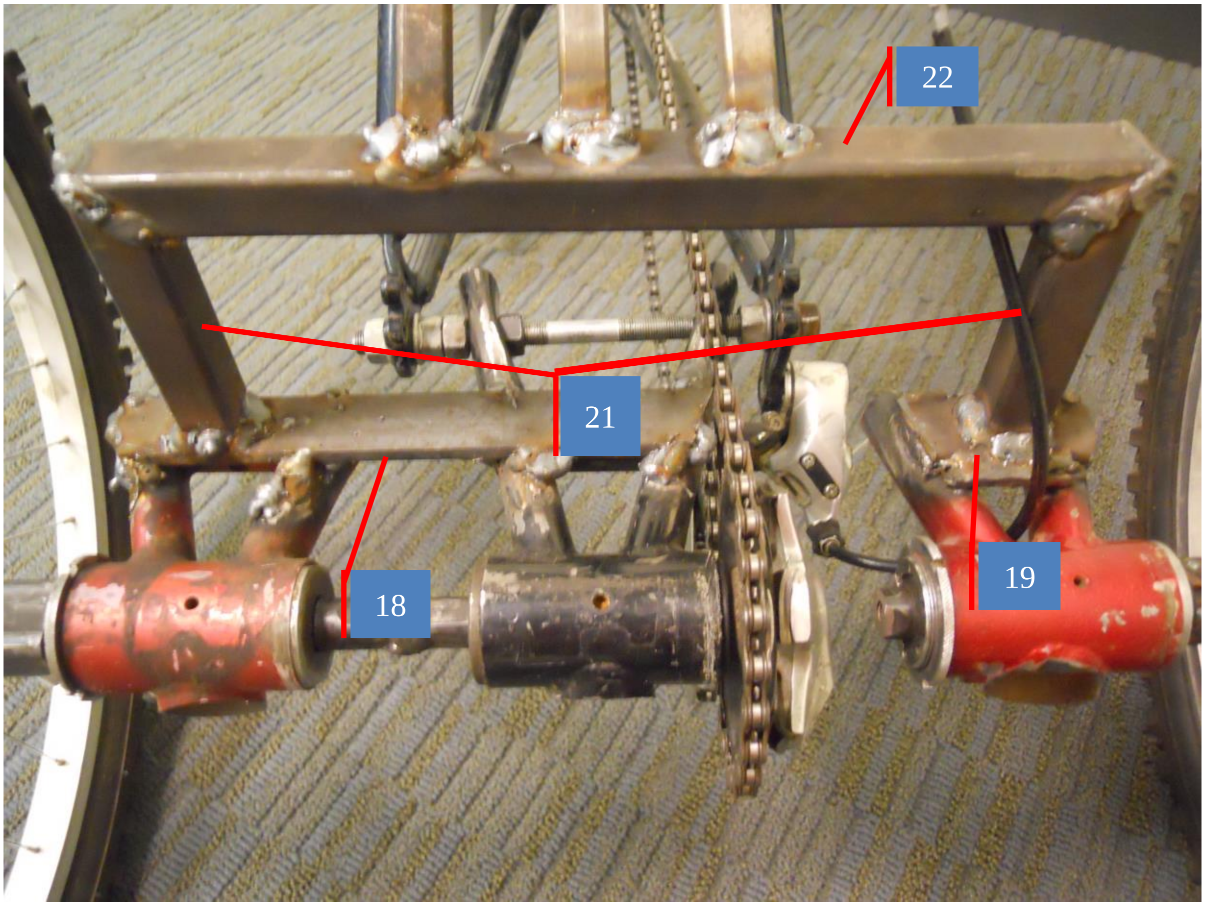
13) Cut hollow steel round stock into 2 ½ x ⅞ in. and 3 ⅞ x 1 1/16 in. (L x D) pieces.

14) Weld the (3) ⅜ in. axle nuts to one end of the larger round stock sleeve.

15) Slide the smaller round stock into the larger round stock until it is flush with the axle nuts.

16) Weld the entire round stock sleeve to the axle of the non-drive side bottom bracket.
* The wheel will attach by threading the axle already contained in the wheel into the sleeve.

Connecting the Drive and Non-Drive Sides



17) Cut ¼ inch bar stock to 7 ¾ x 1 and 2 ⅝ x 1 (L x W x T) inch pieces.

18) Weld the 7 ¾ x 1 x ¼ in. bar stock to the two drive side bottom brackets.

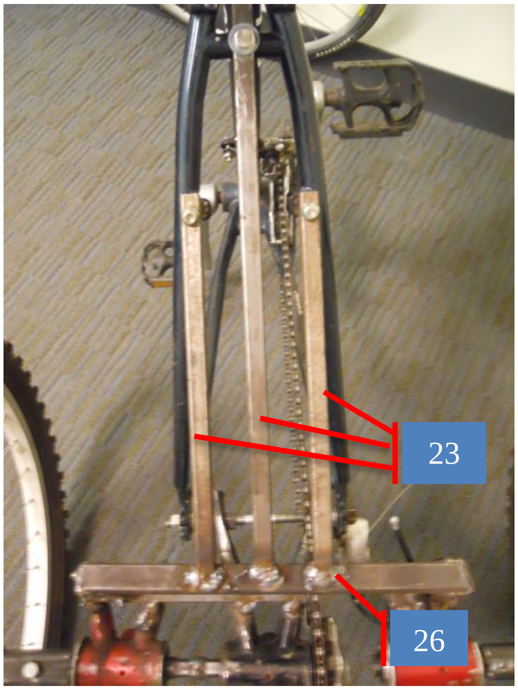
19) Weld the 2 ⅝ x 1 x ¼ in. bar stock to the non-drive side bottom bracket.

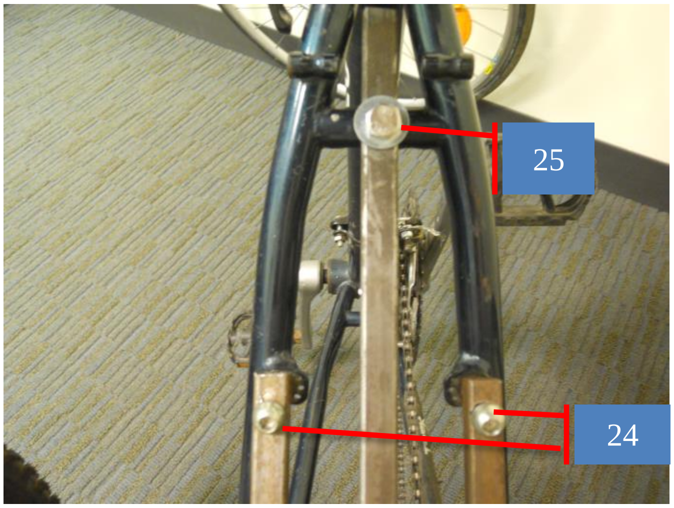
20) Cut hollow steel square stock into two 4 x ¾ in. and one 10 ½ x ¾ in. (L x W) pieces.

21) Weld the two 4 x ¾ in. pieces to each outer bottom bracket vertically.

22) Weld the 10 ½ x ¾ in. piece horizontally to the two 4 x ¾ in. pieces.

Connecting Rear Axle to Bicycle Frame





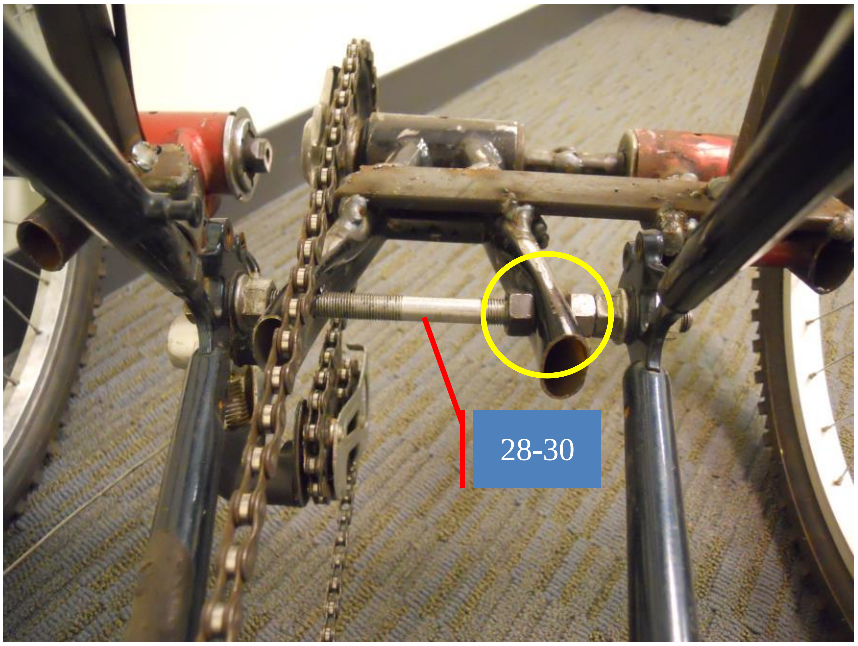
23) Cut hollow steel square stock into two 9 ¾ x ½ in. and one 15 x ½ in. (L x W) pieces.

24) Drill ¼ in. holes through the two 9 ¾ x ½ in. square stock pieces where the rear brake mounts are located.

25) Drill ¼ in. hole through the 15 x ½ in. square stock piece aligning with the hole located in the middle of the bar connecting the two seat stays.

26) Weld the (3) square stock pieces to the top of the 10 ½ x ¾ in. steel stock sitting horizontally on top of the rear axle and align to the holes on the seat stays.

27) Bolt the (3) supporting square stock pieces to the bicycle frame to attach our rear axle prototype.



28) Drill ⅜ in. holes through the bottom bracket containing the sprocket.

29) Thread ⅜ in. rear wheel axle through the two holes with nuts threaded on to secure the design.

30) Attach the rear wheel axle to the bicycle dropouts and secure using axle nuts. Two nuts should be used to secure the prototype to each dropout, and two should be used to hold the bottom bracket centered between the dropouts (yellow circle).

Final Touches

31) Fit chain to appropriate length, and tension the rear derailleur.

32) Paint the prototype and steel components to prevent rusting.

Appendix D: Grant Information

Provided in the table below is information on the available grants which Earn-A-Bike could apply to for funding future projects. The ones we recommend they contact first are highlighted in yellow.

Organization	Address	Contact Info	Trustees	Website
1. The Fletcher Foundation 2. The Stoddard Charitable Trust 3. Wyman-Gordon Foundation	370 Main Street, 6th Floor Worcester, MA 010608	508-798-8621	Warner S. Fletcher, Chair	
Fred Harris Daniels Foundation			Fred H. Daniels II, President Meridith D. Wesby, Vice President/ Administrator	www.bankofamerica.com/foundation
Hoche-Scofield Foundation	225 Franklin St MA1-225-04-02 Boston, MA 02110		Bank of America (Miki Akimoto) Henry B. Dewey Warner S. Fletcher Sumner B. Tilton Jr.	
Albert W. Rice Charitable Foundation	225 Franklin St MA1-225-04-02 Boston, MA 02110	617-434-4898 Melanie.khoury@baml.com	Melanie Khoury (Contact)	https://www.bankofamerica.com/philanthropic/foundation.action?fnld=17
H. Arthur Smith Charitable Foundation	30 Highland St. Worcester, MA 01609-2704	508-753-7100	Matthew F. Erskine (Contact)	
Nathaniel Wheeler Trust	100 Federal St Boston, MA 02110	617-434-4645	Susana Forster-Castillo (Contact)	
Bank of America Foundation				www.bankofamerica.com/foundation
Bank of America Merrill Lynch Philanthropic Management - Charitable Funds				www.bankofamerica.com/grantmaking

Bank of America Foundation - Sponsorships				www.bankofamericasponsorships.com
TD Banknorth Sponsorships (Worcester)				www.tdbanknorth.com/community
TD Banknorth Grants		413-748-8423	Jennifer Gabriel, Community Relations Manager	
Bay State Savings Charitable Foundation	28 Franklin Street Worcester, MA 01608	508-890-9011		www.baystatesavings.com/community.asp
Fallon Community Health Plan	One Chestnut Place/ 10 Chestnut St Worcester, MA 01608	508-368-9523		www.fchp.org/community/foundation
Fidelity Foundation				www.fidelityfoundation.org
The Hanover Insurance Group Foundation	440 Lincoln St, N100 Worcester, MA 01653	508-855-2608	Jennifer Luisa, Assistant Vice President	
Morgan Worcester Foundation	15 Belmont St Worcester, MA 01605	508-755-6111	Gail Morgan, Morgan Worcester	
Saint-Gobain Corporation	One New Bond St, PO Box 15008 Worcester, MA 01605	508-795-2181 donna.d.zalauskas@saint-gobain.com	Donna D. Zalauskas Manager, Communications & Community Relations	
Sovereign Bank New England				www.sovereignbank.com/companyinfo/foundation.asp
UnumProvident	2211 Congress St B201 Portland, ME 04122	207-575-4478	Cary Olson Cartwright Director, Corporate Social Responsibility	www.unum.com
The Health Foundation of Central Massachusetts	446 Main St, 20th Floor Worcester, MA 01608	508-438-0009	Dr. Janice B. Yost, President & CEO	www.hfcm.org

United Way of Central Massachusetts	484 Main St, Suite 300 Worcester, MA 01608	508-757-5631	Tim Garvin, President & CEO	www.unitedwaycm.org
Greater Worcester Community Foundation	370 Main St, Suite 650 Worcester, MA 01608	508-755-0980	Ann T. Lisi, Executive Director	www.greaterworcester.org
People for Bikes	Mailing Address: PO Box 2359 1966 13th St Suite 250 Boulder CO 80302	303-449-4893 info@peopleforbikes.org		http://www.peopleforbikes.org/pages/commnity-grants
League of American Bicyclists-Women Bike Funding		carolyn@bikeleague.org	Carolyn Szczepanski Director of Communications, Women Bike	http://www.bikeleague.org/content/women-bike-funding

The table below lists grants which families can apply to receive funding for purchasing adaptive bicycles, which is also provided in our informational brochure.

Organization	Address	Contact Info	Trustees	Website
United Health Care Children's Foundation (UHCCF)	MN017-W400 PO Box 41 Minneapolis, MN 55440-0041			http://www.uhccf.org/apply.html
Variety Children's Charity	Variety of New England 846 University Avenue Norwood, MA 02062-2631	781-461-1600, ext. 462 info@usvariety.org	c/o Carol Easton, National Amusements, Inc.	http://www.usvariety.org/
Disabled Children's Relief Fund				http://www.dcrf.com/ordereze/default.aspx
Children's Charity Fund		800-643-5787		http://www.childrenscharityfund.org
Wheel to Walk Foundation	PO Box 20146 Portland, Oregon 97294	503-257-1401 info@wheeltowalk.com		http://www.wheeltowalk.com/
First Hand Foundation	2800 Rockcreek Parkway Kansas City, MO 64117	816-201-1569 firsthandfoundation@cerner.com		https://applications.cerner.com/firsthand/
Challenged Athletes Foundation	9591 Waples St. San Diego, CA 92121	858-866-0959 caf@challengedathletes.org		http://www.challengedathletes.org/

Appendix E: Informational Brochure

Front panels of the brochure, which show our adaptive bicycle prototype, the Earn-A-Bike shop hours, and their available programs.

Example of an Adaptive Bicycle

This adaptive bicycle was designed by WPI students in collaboration with Worcester Earn-A-Bike to help people who face issues with balance and coordination.

It is available for use at the shop! Come on in and practice with it!

Come see us!

Located in the basement of Stone Soup: 4 King St, Worcester, MA 01610

Use the back entrance!

Shop Hours & Programs

Volunteering: Saturday 11AM – 2:30 PM
Open Shop: Saturday 2:30 – 4 PM
Youth Shop: Tuesday 3:30 – 6:30 PM
Adult (17+) Shop: Thursday 6 – 9 PM
Women & Trans Night: Friday 4 - 7 PM

www.WorcesterEarnABike.org
Facebook.com/WorcesterEarnABike

(508) 614-9322

Brochure created by WPI Students
Aida Waller, Bror Axelsson, Jaclyn DeCristoforo & Kyla Rodger

Worcester

Earn A Bike

An informational guide on adaptive bicycles

www.WorcesterEarnABike.org

The inner panels include a table describing commercially available adaptive bicycles, as well as cycling organizations and grants families can apply to receive funding for adaptive bicycles.

This Brochure Will Guide You Through:

- Various issues associated with bicycle riding faced by people with cognitive disabilities
- Commercially available adaptive bicycles
- Organizations which utilize or provide adaptive bicycles
- Available grants that help families with expenses

Types of Currently Available Adaptive Bicycles

Type	Description	Pictures
Balance Bicycles	These bicycles have no pedals. Instead the person pushes the bicycle forward with their feet so that they can practice balancing. This bicycle is perfect for those with cognitive disabilities that affect balance.	 •[i]
Tandem Bicycle	A tandem bicycle is a bicycle designed for two riders. These bicycles are great for those who want to bike but cannot support themselves. They come in a variety of types including side-by-side.	 •[ii]
Tricycles	Tricycles are the most diverse of all adaptive bicycles. The third wheel provides extra stability. Due to their nature, this bicycle usually comes with many special features like handcycles or full body support.	 •[iii]
Recumbent Bicycles	Recumbent bicycles are perfect for those who have physical disabilities that make it hard to sit upright. The recumbent seating provides extra back support.	 •[iv]
Handcycles	Handcycles are meant for those with physical disabilities that prevent them from using foot petals. They usually come in the form of tricycles to provide extra stability and foot rests to keep the person's feet safe and in place.	 •[v]
Quadricycles	The only requirement for quadricycles is that they have four wheels, which provides the most support out of any bicycle. This means the bicycle can either be a single rider or a tandem bicycle.	 •[vi]

[i] From 20 Bikes, Trikes and Tandems for children with special needs.
[ii, iii, iv] ibid.
[v] From AmTryke.
[vi] From Disability Cycles | Buy Bikes Online | Get Cycling Online Cycle Shop.

Organizations

Special Olympics: World's largest sporting organization for people with intellectual disabilities; has cycling teams
http://www.specialolympics.org
My Team Triumph: Athletic ride-along program for those who normally would not be able to race
http://www.myteamtriumph.org/
National AMBUCS Inc.: Dedicated to creating mobility and independence for people with disabilities; owns AmTryke therapeutic tricycle
http://www.ambucs.org/
iCan Bike: Hosts nearly 100 biking programs throughout the US and Canada each year including camps to teach children to ride; part of the iCan Shine organization
http://icanshine.org/

Adaptive Bicycle Grants

United Health Care Children's Foundation:
http://www.uhccf.org/apply.html
Variety Children's Charity:
http://www.usvariety.org/
Children's Charity Fund:
http://www.childrenscharityfund.org
Wheel to Walk Foundation:
http://www.wheeltowalk.com/
Challenged Athletes Foundation:
http://www.challengedathletes.org/
Disabled Children's Relief Fund:
http://www.dcrf.com/ordereze/default.aspx