Empowering Individuals with Do-It-Yourself Assistive Technology

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ABSTRACT

Assistive Technologies empower individuals to accomplish tasks they might not be able to do otherwise. Unfortunately, a large percentage of Assistive Technology devices that are purchased (35% or more) end up unused or abandoned [7,10], leaving many people with Assistive Technology that is inappropriate for their needs. Low acceptance rates of Assistive Technology occur for many reasons, but common factors include 1) lack of considering user opinion in selection, 2) ease in obtaining devices, 3) poor device performance, and 4) changes in user needs and priorities [7]. We are working to help more people gain access to the Assistive Technology they need by empowering non-engineers to "Do-It-Yourself" (DIY) and create, modify, or build. This paper illustrates that it is possible to custom-build Assistive Technology, and argues why empowering users to make their own Assistive Technology can improve the adoption process (and subsequently adoption rates). We discuss DIY experiences and impressions from individuals who have either built Assistive Technology before, or rely on it. We found that increased control over design elements, passion, and cost motivated individuals to make their own Assistive Technology instead of buying it. We discuss how a new generation of rapid prototyping tools and online communities can empower more individuals. We synthesize our findings into design recommendations to help promote future DIY-AT success.

Categories and Subject Descriptors

K4.2 **[Computers and Society]:** Social Issues – Assistive technologies for persons with disabilities

General Terms

Design

Keywords

Assistive Technology, Do-It-Yourself, Empowerment, Human-Centered Computing, Online Communities, Personal-scale Manufacturing, Rapid Prototyping

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1. INTRODUCTION

Many people in the US rely on Assistive Technologies to maintain, increase, or improve their functional capabilities. Assistive Technology has been defined to broadly include any product, device or equipment that is acquired commercially, modified, or customized to accomplish something that was not otherwise possible [1]. Assistive Technology covers a wide range of equipment from simple low-tech devices such as handrails and grips, to high-tech equipment that includes power wheelchairs and robots. The US Census has reported that at least 54 million individuals (or 19% of the non-institutionalized US population) have a disability, approximately 13 million people use a mobility aid (wheelchair, cane, or walker), and 11 million people need personal assistance with everyday activities [12].

While there is a large market for both medical and non-medical devices that are used as Assistive Technology, many studies have shown that the overall abandonment rate of Assistive Technology is high: 29.3% overall [7], 8% for life-saving devices [10], 36% for dressing aids [7], 61% for crutches [7] and up to 75% for hearing aids [10]. High abandonment rates leave many individuals without the technology they need and waste time, money, and energy developing and purchasing technology that isn't used.

In a survey of 227 adults with disabilities who use Assistive Technology Phillips found that almost 1/3 of all devices were completely abandoned [7]. She identifies four factors related to abandonment 1) *User involvement in device selection*. She found that user opinions matter, and quotes one participant saying, "Listen to me! I know what works for me." 2) *Ease of procuring the device*. Surprisingly, devices that are easy to obtain (purchased at drugstores, mail-order catalogs, etc) were not always the most appropriate device for the user's needs. 3) *Device performance*. Participants cared about reliability, comfort, ease of use, safety, and durability. 4) *Change in ability (both improvement and decline) and preferences.* User needs, lifestyles, and priorities change over time, resulting in previously used Assistive Technology devices becoming irrelevant to one's current needs.

Phillips concluded that one of the best ways to fight abandonment is to develop policies and services that emphasize consumer involvement and consider long-term needs [7]. We believe that adoption rates can be improved by empowering individuals to create and modify their own Assistive Technology rather than being forced to rely on "off-the-shelf" products.

We are studying how existing DIY culture and tools can be applied to create, modify, or enhance Assistive Technology. A new generation of affordable rapid prototyping tools make it possible for individuals to build and customize physical devices such as wheelchair accessories, prosthetics, and tools to support activities of daily living such as eating, dressing, and accessing a computer.

The success of online communities enables users to share designs, modifications, experiences and inspiration. By empowering individuals with the means and knowledge to create their own Assistive Technologies (and iterate on these designs as their needs change), they will have full control over most of the factors that are problematic in adoption (user opinion, speed of delivery, performance, and understanding user needs).

In this paper we investigate the potential for Do-It-Yourself Assistive Technology. We first present case studies and interviews that investigate opinions and experiences creating customized Assistive Technology. Then, we survey recent cultural trends and tools that we believe can make DIY-AT possible. Next, we discuss how these technologies can improve the Assistive Technology adoption process. We conclude with future DIY-AT challenges: teaching novices and encouraging participation in online communities.

2. Case Studies of Experiences and Interests

This section presents three case studies about experiences and interests in Do-It-Yourself Assistive Technology, where people found their own designs to be better and less expensive than the available off-the-shelf solutions. The first case study is about instructors in an adaptive art class working to help individuals paint without using their hands. The second describes someone who makes a wide variety of Assistive Technologies and has created his own online community to share designs. The third, summarizes findings from interviews with individuals who rely on Assistive Technology about their impressions of DIY-AT.

2.1 Case Study 1: Iterative Design of a Head Pointer for Painting

Motivated by the problem of how to teach art to individuals who couldn't use their hands, instructors at UCP Pittsburgh tried several off-the-shelf and custom-built head pointers that let people paint by moving their head. They spent a year and about $600 searching for a solution that was affordable, lightweight, sturdy, and adjustable. We interviewed one of these instructors to learn more about what they built and their design process. This case study illustrates the drawbacks of off-the-shelf solutions, and how custom-built Assistive Technology can be less expensive; yet work better, than those solutions.

2.1.1 Exploring Off-The-Shelf Solutions

The instructors did not expect that they would develop their own solution, and originally believed that they would be able to find a pre-existing solution and buy it "off the shelf". They began by getting a small grant and started looking at head pointers in catalogs. In general, they found solutions to be expensive (ranging from $100-$300) and found it difficult to tell how well these designs would work in advance.

> "There was no way to make sure the stuff [we saw in the catalogs] worked. We didn't want to waste the money and then find out this stuff didn't work."

Ultimately, they bought several pre-made head pointers (Figure 1, top left), but found they didn't meet their requirements. The biggest problem was that the head pointers weren't steady while in use, and would slide around on the user's head while painting.

2.1.2 Building a Better Solution

After exploring the commercial options available and not being satisfied with the available options, the instructors decided to make their own head pointers that would be more stable and comfortable while in use.

Figure 1. Exploration of head pointers for painting. Off-the-shelf head pointer that was unstable during use, cost $100-300 (top left). Early custom design with a $40 helmet, that was also unstable (note: instructor holding it in place) (top right). A $15 adjustable face shield (bottom left) made the final design (bottom right) less expensive, lighter, and more sturdy than the off-the-shelf solutions.

They did this on their own, and didn't seek ou the help of any Mechanical Engineering or Assistive Technology experts, and didn't look for ideas online.

They combined parts from the products they bought online, and tried attaching them to different kinds of helmets, but found this design also moved too much during use (Figure 1, top right). It wasn't until an instructor brought in a face shield (Figure 1, bottom left) to protect himself from accidentally getting paint in his eye, that they found the perfect base for their head pointer. They used an adjustable face shield that can be commonly bought at any hardware store and costs between $15-$20. They found this solution ideal because it was adjustable, could fit snugly on the head, and stayed still while in use. They removed the screen from the shield, and attached a wooden dowel rod and paintbrush to it on the side (Figure 1, bottom left).

The instructors tested different head pointer designs during weekly art classes, and their participants were very involved in the process and had strong preferences between the different designs. Overall, the participants were very patient throughout the process and even though some designs were uncomfortable and difficult to use, participants were excited to be painting. The instructors don't remember the participants having ideas about how to improve the designs, but they were always willing to try out different designs and were happy with the final design that was comfortable and worked well. These head pointer designs have now been in use for several years, and have empowered many individuals to paint without using their hands. The instructors have made local demonstrations of their design, but have not shared their work with any online communities because they do not know where to share it, and don't know how much time it would take to do this.

2.1.3 Lessons Learned

This case study demonstrates that custom-built Assistive Technology can be less expensive, yet work better than the off-the-shelf solutions. In this example, the instructors first purchased the pre-made solutions, but found they didn't meet their requirements. They were able to identify the limitations of the off-the-shelf solutions, and created their own designs to overcome them. In the end, they spent less on the entire iterative design process than they did on a single off-the-shelf head pointer.

Even though, the instructors were willing to spend money on expensive pre-made solutions they found it frustrating that they couldn't predict had no idea how well they would work. This problem is not unique to Assistive Technology, as many products we buy online include customer reviews and ratings. If the instructors had found online reviews or communities discussing these products, they would have saved a lot of money. It is unfortunate that so much research and experimentation went in to developing these head pointers, but their knowledge and design has not been shared online for others facing this same problem.

2.2 Case Study 2: Building DIY-AT and an Online Community as a Hobby

Our second case study investigates the DIY-AT experiences of Jeary[1], an able-bodied retired finance professional who has an engineering degree and has been designing and building adaptive technology for 40 years as a hobby. He has created many designs for a wide range of applications and physical disabilities and posts them to his own website (workshopsolutions.com) that features over 170 Assistive Technology designs (a mix of his own designs, and designs that have been submitted by others). The primary goal of the website is to share Assistive Technology designs with others, with the aim that they can make the designs themselves.

Figure 2. Homemade miniature wheelchairs – the "founding project, 1972".

2.2.1 Inspiration and Design Work

Nearly 40 years ago, Jeary walked into a room full of paraplegic children sitting on floor mats or adult sized wheel chairs that were too big. This inspired him to create his first adaptive device: miniature wheelchairs in the shape of go-karts. The miniature wheelchairs swiveled, had brakes, and were made of ½" plywood with upholstered seats, back cushions, and a swinging utility tray for getting in and out easily. On delivery of the carts, the children were instantly mobile. Not long after, a lightweight stick was added to each miniature wheelchair to allow the children to push elevator buttons and move between floors. These miniature wheelchairs fit the children well, and were functional, popular, and used for several years (Figure 2).

Since then, Jeary has worked out of his home workshop to create hundreds of devices for people with disabilities. Located in a 12'x14' room in his basement, he uses standard hand tools plus a bandsaw, table saw sander, drill press, router table, welding and soldering equipment, and plastic bending and forming tools. In an adjacent furnace room, he stores a large supply of wood, metal, foam, leather, and Velcro. He has helped people with motor impairments do things that would normally be very difficult, such as eating with one hand, operating a TV remote control without fingers, and skiing without lower limbs.

Jeary's homemade adaptive devices are much more economical to build than similar products that may be commercially available. For instance, a homemade wheelchair cup holder posted on his site costs less than $2 to make but similar products from medical supply companies have a suggested retail of $110 (Figure 3, left and right). In his experience, Jeary believe that consumers tend to think that because products are from medical supply companies they're better but, he asserts "It's just more expensive because it's 'medical'. You can buy something and just modify it for less."

"THE PROBLEM: To provide a multipurpose drink holder allowing both hands to be free to control wheelchair movement.

THE SOLUTION: A wide variety of holders can be built quickly and cheaply using 4" cut off lengths of 3" diameter PVC pipe. Lightly sand and varnish for a finished look. Drill cross holes of appropriate diameter at the bottom to glue in lengths of black fiberglass rod from a discarded umbrella. Appropriate brackets can be made from scraps of PVC and bonded strongly with PVC glue or attached with nuts and bolts depending on where on the wheelchair/scooter they are going to be used."

Figure 3. Jeary's homemade wheelchair cup holder (left), and a cup holder with u-bolt wheelchair Rail Mount by RAM for suggested retail of $110 (from1800wheelchair.com, right). Text from Jeary's webpage describing the solution (bottom).

2.2.2 Creating an Online Community to Share Designs with Others

Jeary has not patented any of his ideas and freely shares them on a website he and his son created, funded, and currently maintain. Originally launched in 1998, the website was created to serve persons with disabilities, family members, or caregivers who are looking for an adaptive device that they can build. Jerry claims that his designs aren't high tech, and anyone who is somewhat handy should be able to build them. The site has not changed much from its original inception and is simple by design.

As of this writing, 47% of the adaptive devices posted on Jeary's website were added by site visitors, many of whom have contributed more than once. Most of the contributions are made by individuals, but some are made by small teams of designers

[1] Our participant asked that we use his real name in this paper, and include the real name of his website.

and builders. Some contributors are handy people wanting to help and may have been inspired by Jeary's work or personal experiences with the disabled community. Others are caring for loved ones and want to share solutions that have worked for them. It's a small online community in which visitors contribute content via email. For ease of use and consistency, contributors follow a standard format (Figure 3, bottom) of submitting one paragraph describing the problem, one paragraph for the solution, and up to six photos. The submissions are revised to follow the standard format, often resizing images and revising the copy to fit within the "Problem" and "Solution" framework but, within a few days, the contribution is manually posted to the website for all to browse and freely use or share.

According to a visitor counter on the website, it has received almost 70,000 visitors. Jeary receives email inquiries pertaining to 1) how the devices can be purchased, 2) details about how to build an idea, and 3) requests to have something built for them. For those inquiring about purchases, Jeary clarifies the concept of the site and explains that nothing is for sale. Although many people ask Jeary why he doesn't try to make a profit, he exclaims, "This has nothing to do with money." With a few exceptions, anything that Jeary builds for others is at no cost. He buys all materials at his own expense and perceives it to be just like any other hobby related cost. "I bet I don't spend more in a year than a golf enthusiast does," he says. Instead of selling online to those who inquire, he often provides very detailed information and drawings as to how they can create possible solutions for themselves. As for those requesting something to be built, Jeary explains:

> "I can't help all of these people because they're in Peru or somewhere and I'm over here… I need to really be in front of the disabled person to see their unique situation and come up with a good solution."

2.2.3 Summary and Implications for Future DIY-AT

Jeary's work and the number of contributors posting to his website illustrate that there are people who are dedicated to helping others make their own Assistive Technology, and are willing to donate their ideas online in an effort to freely help people with disabilities. The inquiries received from people looking for solutions online, trying to pay for a custom build, and asking for more detailed instructions are evidence that there is consumer demand for homemade adaptive devices and people are building things from the ideas shared. Further, users of his site have found cost benefits when comparing a homemade device to a commercial one. Jeary's humble site, absent of automation and newer technology, has mostly a local Canadian audience. Perhaps a more robust site, could grow a larger online community, and gain broader outreach.

2.3 Exploring the Potential of DIY-AT

We gauged potential interest in DIY-AT from motor-impaired individuals who hadn't made their own Assistive Technology through face-to-face interviews. We interviewed four individuals (1 female) at United Cerebral Palsy Pittsburgh about their experiences with Assistive Technology, and talked about what modifications they would want to make to their current Assistive Technology (assuming there were no limitations). All participants had concrete ideas for modifications they felt would increase their comfort, safety, or quality of life. Surprisingly, almost all of these modifications would be extremely simple and affordable to implement.

We conducted two interviews in pairs, and all participants were power wheelchair users for over 8 years. In Group A, P1 (33, male) and P2 (21, male) controlled their power wheelchairs with their hand using a joystick. In Group B, P3 (30, female) had an Augmentative and Alternative Communication (AAC) device mounted on her chair. P4 (54, male) had an upper extremity impairment and controlled his power wheelchair using a joystick mounted near his chin. A preset list of questions was used in both groups, and participants in Group B were asked about modifications group A were interested in.

2.3.1 Modification Desires

None of our participants had experience modifying their Assistive Technology beyond simple customizations such as decorating their wheelchair with stickers or keychains, or hanging bags from the chair's frame. All of the modification interests our participants mentioned were related to their power wheelchairs (likely since this is such a crucial piece of Assistive Technology in their lives). All of our participants had modifications ideas if money, difficulty, and ability were not a factor. The majority of these modifications were relatively minor and easily do-able. We summarize the modifications our participants identified below.

Modification Interest in Group A

Group A (P1 and P2) had a lot of ideas to modify their wheelchair, and they felt strongly that their wheelchairs should have more car-like features (since their power wheelchairs were as expensive as a car). The two most difficult modifications were a bigger motor (so they could go faster), and hydraulic shocks (for a smoother ride). However, they were equally interested in adding safety lights (turn signals, head, and tail lights) to their chair and having their chair play music (while waiting or travelling). They wanted the chair to have speakers and be the source of the music itself, rather than have a personal device (such as a cell phone or mp3 player) do this.

Both participants had an acrylic tray over their lap that was always attached to their wheelchair. They expressed in interest in modifying these with customizable edges (adjustable color and height) to prevent things from falling off the tray. They also wanted a place to securely hold objects they used frequently (cups, cell phone, remote controls), and easily reach drink straws without having to contort their face, or risk poking their eye.

Modifications Interests in Group B

Group B (P3 and P4) also had many ideas how to modify their chair, but they tended to be more interested in the comfort than the function of their chairs. Both participants expressed interest in having the seat of their chair be heated and be able to vibrate (for a massage).

P3 was interested in having safety lights on her chair, but P4 was not.

When we asked about being able to play music from her chair, she demonstrated that she was able to play MP3 files through her AAC device. She frequently used this feature while volunteering at a local children's hospital to entertain children. She usually plays seasonal songs for the holidays and the local football team. P4 liked the idea of having access to music, and said he would want to have it come out of his headrest.

P4 had the simplest modification requests: access to the time and water. He wished he had access to a clock on his wheelchair so he wouldn't always have to ask someone else for the time. He wanted to mount the clock under his wheelchair's display (Figure 4, right), but didn't know how to do this. He was interested to learn that P3 had a small clock mounted to a bar on her chair (Figure 4, left).

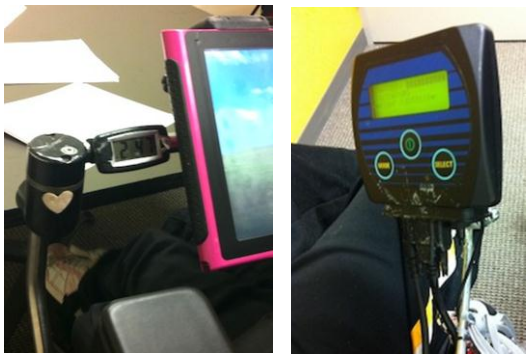

Figure 4. P3 has a small clock to the left of her AAC Device (left). P4 wished he had a clock under his power wheelchair's controller (right).

P4 drives his wheelchair using a joystick with his chin, and switches modes using a push button mounted on the opposite side of his head as the joystick. Unfortunately, the switch is on the same side as his Drink-Aide (an adjustable straw that is too short for him and hard to reach without accidentally hitting the switch). He wanted to have the Drink-Aide mounted somewhere where it would be more comfortable and not interfere with his wheelchair's controls.

2.3.2 Reactions to DIY-AT

After discussing modification interests, we asked our participants their opinion about creating their own Assistive Technology, and explained personal-scale manufacturing to them (Section 3.1).

Participants P1 and P2 immediately saw the potential for DIY-AT and these new technologies, and thought it was the way of the future, and something they should learn more about. However, they were concerned about making changes to the chair that would risk breaking the equipment, or violate the warranty. They felt uncomfortable letting a 3rd party make customizations, but would be more comfortable if they were involved in the process.

P3 saw building her own Assistive Technology as a way to control the aesthetics of her devices. She expressed disappointment that the color of her wheelchair chair and AAC device did not match (and were not her favorite color).

P4 had no interest in the aesthetics of his devices, only in their function. Unlike P1 and P2, he was not concerned about using custom-built parts on his wheelchair if it meant he didn't have to rely on someone else to fix them. He stated, "When things break, I stay in bed", referring to the two months he had to stay in bed when the controls on his wheelchair broke.

2.3.3 Summary of Interview Findings

Overall, our participants were interested in customizing their Assistive Technology, and had many achievable ideas for modifications they would want to make. Participants who were concerned about these solutions impacting the chairs' performance (or their warranty) were willing to modify their equipment so long as they were involved in the process. Another participant saw being more involved in making his own modifications a way to gain independence. Unsurprisingly, aesthetics were found to be an important consideration for some. We feel that these findings are very promising for the potential and success of DIY-AT.

3. Relevant Tools and Online Communities for the Do-It-Yourself Revolution

The popularity and increasing growth organizations such as Make Magazine (http://www.makezine.com) and Martha Stewart (http://www.marthastewart.com) illustrate the DIY revolution happening now. A renewed interest in making things is due to peoples' desire to save money, customize goods to fit their interests and needs, feel less dependent on corporations [5]. Today, this interest spans a wide range of activities from gourmet cooking, fashion, home improvement, and electronics. This culture highlights a set of values where sharing, learning, and creativity are valued over profit and social capital [4]. A culture where people are interested in modifying or creating is not new, and has appeared throughout history notably through amateur radio enthusiasts in the late 1920s, and model railroad enthusiasts in the 1950s [6]. According to Von Hippel, 10-40% of users engage in developing or modifying products [13].

> "Users that innovate can develop exactly what they want, rather than relying on manufacturers to act as their (often imperfect) agents. Moreover, individual users do not have to develop everything they need on their own: they can benefit from innovations develop and freely shared by others" [13].

This section surveys recent innovations and trends in personal-scale manufacturing and online communities, and past work building customized Assistive Technology.

3.1 Rapid Prototyping Tools for Personal-Scale Manufacturing

Over the past decade a new generation of *rapid prototyping tools* (machines that manufacture objects quickly so they can be used in the iterative design process; the quality and durability of their output varies) have emerged that have the potential to make *personal-scale manufacturing* possible. "Personal-scale manufacturing tools enable people that have no special training in woodworking, metalsmithing, or embroidery to manufacture their own complex, one-of-a-kind artisan-style objects [3]. This technology provides new opportunities for individuals with disabilities to build their own physical objects, using tools such as Computer Numeric Controlled (CNC) tools that can precisely cut or build a variety of materials. Such tools include 3D printers that can build solid objects out of plastic, laser cutters that can precisely cut (or etch) flat materials (such as cardboard, acrylic, wood, and metal), and multi-axis milling machines that can transform metal into almost any 3D shape.

3.1.1 Tools that Make Building Accessible

Traditional manufacturing machines (band saws, lathes, and drill presses) frequently require many physical requirements of their users. These include the ability to stand, precise manual dexterity, and accurate vision, all of which limit whom can operate these machines. Furthermore, operating these machines requires special training and knowledge, and can be extremely dangerous when misused. CNC machines remove many of these barriers since they are computer-controlled, and the main task of the user is to create the design, and to supervise the machine during the build process. This development provides an exciting opportunity for individuals without Mechanical Engineering or manufacturing backgrounds to build things. To create something for one of these machines, a user only needs to be able to access a computer and create (or download) a file in the correct format.

Over the past decade, these machines have become more affordable and ubiquitous. In the past, access to these machines was predominantly limited to large manufacturing companies and research labs because the machines were prohibitively expensive for other organizations. However, there are now CNC machines that are affordable enough for people to have in their own homes or their local community. For example, the MakerBot (http://www.makerbot.com) is a 3D printer that connects to a desktop computer via USB and builds 3D objects by layering plastic. Costing under $1300, the MakerBot is stark contrast to professional 3D printers that cost tens of thousands of dollars and use expensive materials. For example, a hand splint could be easily printed on a MakerBot using less than $1 of plastic filament. The MakerBot is currently sold as a kit that the end-user must assemble (much like the Apple I from 1976), so it may not be an appropriate choice for someone with limited mobility now, but it is likely that more accessible options will become available in the near future. In the meantime, community-oriented ownership, such as libraries or disability centers, will enable individuals with disabilities to take advantage of the opportunities offered by such devices to create DIY-AT.

With the cultural movement of people interested in DIY activities, there are a growing number of people buying (or building) CNC machines for their homes. Additionally, shared and public workshops such as Hackerspaces (http://www.hackerspaces.org) and Fabrication Labs (http://fab.cba.mit.edu) are becoming more common, and give individuals the option to rent time on shared machines. Those who do not have access to nearby CNC machines can manufacture almost any part using online services such as Ponoko (http://www.ponoko.com), and Shapeways (http://www.shapeways.com), and eMachineShop (http://www.emachineshop.com). These companies tend to offer high quality manufacturing for a variety of services including 2D and 3D manufacturing of metal, wood, glass, and plastic. They offer reasonable turnarounds, competitive pricing, and support small order volumes.

As manufacturing become more accessible, it is possible for almost anyone to become a machine operator, but an important question is how novices will create designs. Following in the footsteps of software designed to help non-programmers build and customize software such as Alice (a 3D animation programming environment, http://www.alice.org), there has been an influx of software projects to help non-engineers build 3D models. Examples include Google's Sketchup (http://sketchup.google.com), 3DTin, (http://www.3dtin.com), and Tinkercad (http://www.tinkercad.com). These applications are WYSIWYG (What You See Is What You Get) and output a standard format.

3.2 Sharing Ideas and Online Communities

The origins of open-source software, or freely sharing source code, can be traced back to the 50s when researchers started sharing software in user forums. Since then, open-source software has become tremendously successful and provides a reasonable alternative to mass-marketed software, at a fraction of the cost (or no cost). Open-source hardware is a recent parallel to the open-source software movement: the same values and ideas are present where designs, materials, discussions, and source code are all publicly available.

One of the most successful open-source hardware projects is the Arduino (http://www.arduino.cc), a microcontroller that is relatively easy to interface with, yet extremely powerful and versatile. The Arduino platform has been used by engineers, hobbyists, and children for a variety of projects including home automation, robots, and art projects. The Arduino platform was originally created to make it easier for non-engineers to build electronics projects. Since its creation, thousands of people have created projects using the Arduino by building their own Arduino board (or one of the dozens of Arduino-compatible boards), or buying kits that interface with an Arduino and include all the parts required to complete a project.

3.2.1 Relevant Online Communities

There are many successful online communities that help individuals share designs, inspiration, and experiences to fuel the open-source movement. Example sites include the Make Magazine Blog (http://blog.makezine.com), Instructables (http://www.instructables.com), and Thingiverse (http://www.thingiverse.com).

The Make Magazine Blog posts interesting projects and news from both professionals and amateurs in the DIY community. Posts are made by members of an editorial staff and who post anything from interesting research innovations, interviews with professional makers, and first time projects. While the blog is curated, it also engages novices through in-post discussions, active forum discussions, and promoting an inclusive community.

Instructables is an online community whose members can easily share how to make anything. This site supports sharing by allowing photo and video uploads and posting step-by-step instructions. Contributors learn from other members who rate their projects or ideas and leave comments that often lead to improvements. Forums and Groups also allow members to engage in specific categories with like-minded people.

Thingiverse is an online community for sharing completed designs and works-in-progress. This website encourages its members to upload all of the digital files required to build anything. For example, Thingiverse hosts all the digital files and information you would need to print a robot on a 3D printer. Thingiverse supports the needs of both expert designers who want to disseminate their work, and novice makers who don't know how to create 3D models, but have access to rapid prototyping tools.

3.3 Prior DIY-AT Projects

3.3.1 Low-Tech Custom-Built Assistive Technology

While we believe that rapid prototyping tools and online communities have the potential to transform custom-built Assistive Technology, there have been successful DIY-AT projects that do not use these modern tools. For individuals living in Third World countries, building their own Assistive Technology may be the only option, since they may not have access to pre-made Assistive Technology or insurance. Werner has developed a guide for community health workers, rehabilitation workers, and families to make Assistive Technology for disabled village children [14]. This guide is sold as a printed book, and is also available freely available online (http://www.hesperian.org). This guide summarizes how to build a wide range of Assistive Technology such as splints and braces out of found materials such as sticks, branches, or cups.

Therese Willkomm is known as "The McGyver" of Assistive Technology, and has written books and given workshops on how to help people solve their own needs. Her solutions are designed to be affordable and use inexpensive and readily available materials such as tapes, adhesives, fasteners, and recycled materials. Her work includes mounting and modifying switches, and creative fastener and padding solutions [15].

Werner and Willkomm's work is tremendously innovative, and has solved important Assistive Technology needs. However, their manufacturing techniques are limited by what can be made without electricity and using found objects. We feel this impacts the items durability, generalizability (i.e. Werner's work is mostly for small children), and aesthetics. These limitations may impact the adoption rate and potential for long-term use solutions. While their work is currently online, we did not find online communities discussing or extending their work.

3.3.2 High-Tech Custom Built-Assistive Technology

Inspired to help a Graffiti artist with Amyotrophic Lateral Sclerosis (ALS) a small team of professional artists and programmers spent two weeks to create an open-source eye-tracking apparatus that lets people draw with only their eyes. This team developed the EyeWriter (http://www.eyewriter.org) a $50 eye tracker that uses a webcam and open-source software. Since its initial development, this project has grown and people all over the world have built their own EyeWriter as both an art tool, and as an inexpensive eye tracker.

The Open Prosthetics Project (http://www.openprosthetics.org) is an open-source collaboration between users, designers, and funders to develop and share prosthetic innovations. This initiative includes several ongoing projects, where all of the design work is openly published online. They encourage end users to provide design ideas and evaluate designs, and mail them products to test. One of their projects is the Trautman Hook Project, to revive a design from 1925, which is no longer commercially produced. This group analyzed the original patents of this device and created 3D models of this hook, and printed them in metal using different rapid prototyping machines. (http://openprosthetics.wikispot.org/Trautman_Hook)

These high-tech projects are lead by professionals, but illustrate the potential for rapid prototyping tools and online communities to create and promote custom-built Assistive Technology.

4. How DIY-AT can Improve the Assistive Technology Adoption Process

In this section, we analyze Rogers' five stages of adoption, and discuss how each stage relates to Assistive Technology adoption, and how online communities or rapid prototyping can help in each stage. We then discuss how the stakeholders involved in the adoption process and the length of this process can impact the adoption of the Assistive Technology.

4.1 Rogers' Five Stages of Adoption

Rogers [9] identified a five-stage adoption process that an individual or group makes for new innovations. The first three stages build up to the individual choosing the innovation, and the last two focus on what happens after it has been adopted. We present each stage and discuss how rapid prototyping and online communities can help individuals adopt the most appropriate Assistive Technology.

1) *Knowledge* (or awareness) of the technology, including basic knowledge of how it functions, and how to operate it. Online communities have made it easier for individuals to learn about new technologies, and websites such as YouTube (http://www.youtube.com) have made it easier to understand how technologies work. In a study of how people search for craft knowledge (a very popular DIY activity) on the Internet, Torrey found that individuals frequented blogs, forums and mailing lists, or relied on their social networks to stay informed [11].

2) *Persuasion* (internal or external) to adopt the technology. Common questions adopters have in the second stage are "What are the technologies' consequences?" and "What will be the advantages/disadvantages for my situation?" Individuals considering new Assistive Technology could greatly benefit from online communities to better understand the technologies and the experiences of others. "When someone who is like us tells us of their positive evaluation of a new idea, we are more often motivated to accept it" [9].

3) *Decision* to adopt, or reject the technology based on information gathered in the previous stages. In this stage, individuals commonly test the technology before making an adoption decision. Some individuals are able to test out Assistive Technology through government-supported lending libraries (such as Pennsylvania's Assistive Technology Lending Library: http://disabilities.temple.edu/programs/assistive/atlend), but these resources do not always have the technology the individual is looking for. Rapid prototyping offers an alternative solution: fast and affordable manufacturing of prototypes a user can interact with to test the technology. For example, an individual could quickly and inexpensively test a hand brace by downloading a design from Thingiverse, print it out of plastic (an inexpensive material) to see if the size and shape are comfortable. If they like it, they could make it out of a more durable material (metal).

Rogers states that the trial of a new technology by a peer or opinion leader can substitute for the adopter using the device him/herself in this stage. Online communities can serve a useful role here because individuals can share stories (and videos) about their experiences. A relatively common practice on YouTube currently involves users making videos while unboxing (unpacking) new technology, or posting short videos (or screenshots) of themselves interacting with it.

4) *Implement* (or test) technology by incorporating it into one's life and putting it to use. While interacting with this technology, the user may find modifications that they want to make to it (a term Rogers calls "re-invention"). He points out that research and development agencies frequently see re-invention as negative (because they know best). However, re-invention is often beneficial for the adopter:

> "Flexibility in the process of adopting an innovation may reduce mistakes and encourage customization of the innovation to fit it more appropriately to local situations or changing conditions. As a result of re-invention, an innovation may be more appropriate in matching an adopter's preexisting problems and more responsive to new problems that arise..." [9]

We see rapid prototyping and online communities playing a large role in this stage by helping individuals identify solutions to problems they have with a technology, learn how to fix them, and engage in re-invention.

5) *Confirmation* that the technology is appropriate (or not), after it has been in use for a significant period of time. During this stage, the individual seeks reinforcement of their decision, and may choose to do so through research or talking with others who have also adopted the technology. The same online communities that apply to the knowledge and persuasion stage can play a positive role here to help individuals decide if a technology is appropriate.

4.2 Stakeholders

Dawe found that many parties (parents, teachers, clinicians, friends, caregivers, and Assistive Technology specialists) can be involved in the different stages of Assistive Technology adoption

[1]. Her work found that having multiple parties involved could lead to tension that creates unintended challenges. We believe that empowering individuals to research and create their own Assistive Technologies may alleviate the challenges caused by having multiple opinionated stakeholders. Furthermore, affordable and rapid production enables individuals to try out more technologies (reducing the burden of having to make only one choice). Additionally, having access to online communities of others who have used, modified, or designed their own technology can provide valuable decision making information.

4.3 Duration of Adoption Process

Currently the time between the decision stage and implementation stage for Assistive Technology can be very long. Our interview participants reported that it took at least a year to get their power wheelchair. This delay can be due to a number of factors, but frequently is due to having to negotiate with insurance companies and other agencies. Dawe cites this delay as a major problem in the adoption process because an individual's needs may have changed (and they may not even need the device) by the time it arrives [1]. DIY-AT can remove these barriers, helping people gain access to the technology they need faster in both the decision and implementation stages of adoption.

5. Future Challenges and Conclusion

5.1 Empowering Novices

A key element to DIY-AT being a success is empowering individuals to share and create Assistive Technology designs. Social websites that let users download open-source designs (such as Thingiverse) enable individuals to share, iterate upon, and discuss designs. While these sites offer a unique way to build a community and distribute designs, they currently do not provide support to help novices customize the designs.

We believe that tools that let novices easily customize pre-existing designs will play a crucial role in the future of DIY-AT. These tools should let users easily make minor changes such as adjusting the dimensions of the design, and also help them make more major changes (such as changing how it interfaces with other technology). In addition to teaching how to use this new technology, we must teach end users how to assess their needs and identify appropriate solutions that match their needs.

5.2 Contributing to Online Communities

In our case studies, we told the story of individuals who had created their own Assistive Technology, but haven't shared their designs with any mainstream communities. Some of the reasons they haven't shared their designs is because they don't know what high-traffic sites to post their work, and feel that they do not have the time to find this community. In order for online communities that support DIY-AT to succeed, they must be easy to contribute to, easily discovered by online search, and be well known within the community.

5.3 Conclusion

This paper has explored the potential of DIY-AT and illustrated how it can increase the adoption rate of Assistive Technology. Our case studies have illustrated that it is possible to custom-build Assistive Technology that is less expensive, and preferred over off-the-shelf solutions. Our interviews with individuals who rely on Assistive Technology show that they have concrete modification ideas that are easily achievable. Additionally, they have an interest in learning how to make modifications on their own and to be involved in the process. We believe that the combination of personal-scale manufacturing and online communities provide a unique opportunity to empower individuals to create their own Assistive Technology that is more likely to be adopted than off-the-shelf solutions.

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