Leveraging Blind Woodworkers’ Practices to Develop Inclusive Instruction

by

Eric Forest, RGD

Submitted to OCAD University

in partial fulfillment of the requirements for the degree of

Master of Design in Inclusive Design

Toronto, Ontario, Canada, April, 2019

Author's Declaration

I hereby declare that I am the sole author of this MRP. This is a true copy of the MRP, including any required final revisions, as accepted by my examiners.

I authorize OCAD University to lend this MRP to other institutions or individuals for the purpose of scholarly research.

I understand that my MRP may be made electronically available to the public.

I further authorize OCAD University to reproduce this MRP by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

Signature ____

Abstract

The goal of this study is to identify teaching strategies that can help visually impaired students to participate in design and design related education, and by extension, professional practice. The motivation for developing inclusion in STEAM classrooms and design studios is based on past literature demonstrating that diverse and empathetic groups of problem solvers are highly effective, and that visually impaired students have had historically limited access to education and employment opportunities in general. This study suggest that, based on the for-us-by-us woodworking courses developed in blind communities, woodworking is a viable form of design and STEAM education for visually impaired students, and hence can serve as an example case study for understanding how we can implement more inclusive education. As findings we present 10 teaching principles which instructors can use to make their woodshops accessibly to blind woodworking students, and consider the likely benefits of woodworking on student life.

Keywords

applied arts, blind, creative, education, design, DIY, DIY-AT, for-us-by-us, inclusion, inclusive, learning, maker, makerspace, STEAM, STEM, visually impaired, woodworking

Acknowledgements

I am thankful for the contributions and assistance of:

LightHouse for the Blind and Visually Impaired and the staff at Enchanted Hills.

Woodworkers like George, Jeff, and Clay.

Two anonymous contributors.

And my advisor, Sowmya Somanath.

Dedication

For those who prefer to create instead of comment, or at the least whose comments are creative. Whatever apprehending underscores your joy of making, know there is more than a little comprehension in it.

The poet's eye, in fine frenzy rolling,
Doth glance from heaven to earth, from earth to heaven;
And as imagination bodies forth
The forms of things unknown, the poet's pen
Turns them to shapes and gives to airy nothing
A local habitation and a name.
Such tricks hath strong imagination,
That if it would but apprehend some joy,
It comprehends some bringer of that joy;

Shakespeare, *A Midsummer Night’s Dream. 5.1.1842-1849*

Table of Contents

Table of Figures

Chapter 1: Introduction

“The real problem of blindness is not the loss of eyesight. The real problem is the misunderstanding and lack of information which exist. If a blind person has proper training and if he has opportunity, blindness is only a physical nuisance.”

- Iowa Commision for the Blind.

1.1 Motivation

Reliance on visual education has made educational pathways that lead to employment in design fields inaccessible. Without access to design training and education, blind students suffer a reduction in opportunities to shape their experience in favourable ways as professional design practitioners creating useful designs.

The barriers to training and opportunities to education that affect blind students today are a historical problem. In a 1970 public address, Kenneth Jernigan, longtime President of the National Federation of the Blind, read aloud a admissions denial one of his members received:

> *Dear Blank:*
>
> *We have received your application for admission and are very impressed with the academic record you have established in high school.*

In checking your application I notice that you are blind. At this time, ORU does not have the facilities to accommodate blind students. There is a possibility that some type of program will be initiated in future years; however, at this time, I regret that we will be unable to admit you.

As recently as 2012, ninety-eight percent of Canadian students with disabilities (756,000 of which are visually impaired) report that their disability has directly impacted their post-secondary education in dramatic ways (Bizier, Till, and Nicholls, 2014). The 2012 Canadian Survey on Disability found that 21.8% of students aged 15-24 with a learning disability also suffered a seeing/hearing disability, and the co-occurrence in adult learners ages 25-64 increases to 50% (Bizier et al, 2014). Confoundingly, 89% of all respondents with a seeing disability also reported at least one other type of disability (Bizier, Ricardo and Walpole. 2012). Among visually impaired students aged 15 and up, 67% reported that their disability impacted their choice of courses/career, 51.8% took fewer courses due to disability, 48.1% changed course of studies due to disability, and 46.3% reported that people avoided/excluded them in school due to disability (Bizier et. al, 2012).

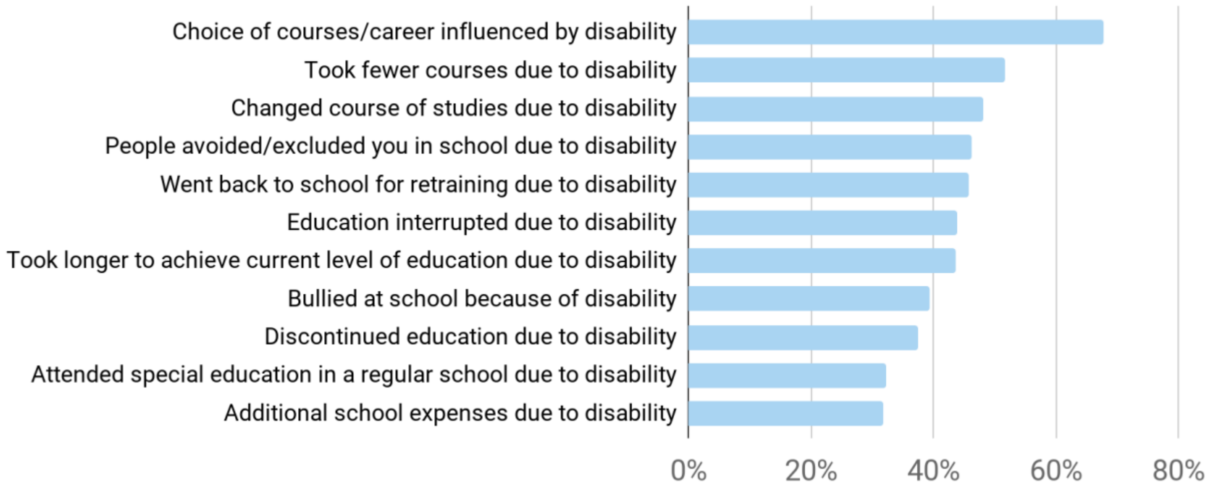


Figure 1: Percentage of Canadians with a seeing disability, aged 15 and older, who experienced a particular impact on their education as a result of their disability. Source, Bizier et al, 2012.

Ongoing exclusion from education has impacted the employment rate of visually impaired students. More than half (55.2%) of adults aged 15 to 65 with a seeing disability are not in the workforce (Bizier et al, 2012). In comparatively accessible design fields like software development, only 1% of developers are blind in America (Stack Overflow, 2017), even though 2.83% of working aged adults have a visual disability categorized as blindness (National Federation of the Blind, 2016). The employment rate for adults without any disability, in general, in Canada, is 73.6%. But the employment rate of adults with a seeing disability is only 37.6%, while a further 25.2% report they were refused a job or an interview because of their disability (Bizier et al, 2012). The same study indicates that inadequate “training and experience” accounts for 26.7% of visually impaired people’s unemployment.

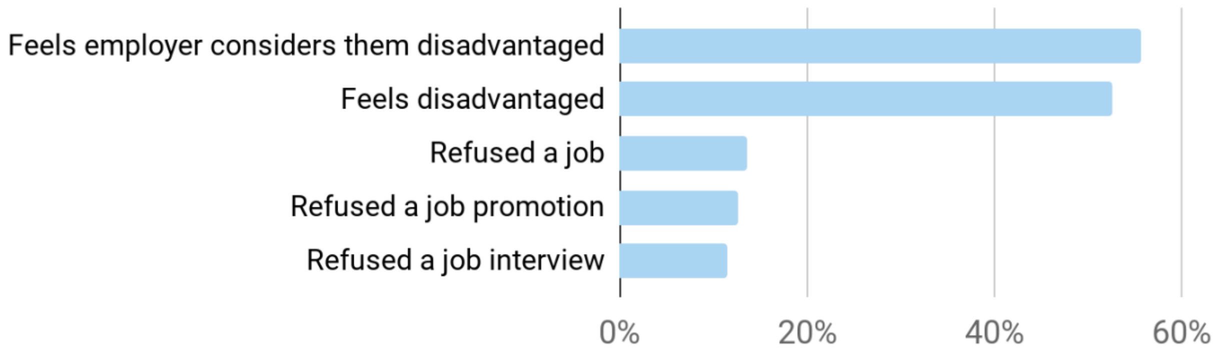


Figure 2: Percentage of Canadians with a seeing disability, aged 15 years and older, who perceived a particular discrimination or disadvantage involving their employment. Source, Bizier et al, 2012.

Of those Canadians with a seeing disability who are employed, 55.6% feel their employer considers them disadvantaged (Bizier et al, 2012), which supports Lindsay and Cancelliere's claim that many employers and educators lack what they term "disability confidence" (2018).

"Disability confidence" refers to behaviours like positive attitudes, empathy, and appropriate communication skills, but also the knowledge to serve (accommodate) disabled people (Lindsay and Cancelliere, 2018).

A lack of disability confidence has a cyclic effect. Limited accommodations for students with disabilities in schools means fewer disabled students graduate. As a result, fewer disabled graduates are employed by employers, reducing the employer's disability confidence. The products which those employers produce - which includes on-the-job training and the products which facilitate it - also suffer from disability confidence, and the cycle repeats. To replace this cycle of exclusion with a cycle of inclusion, an intervention is required, either through access to education, to design professions, or to design tools, whereby users can participate in design in a meaningful way (Figure 3).

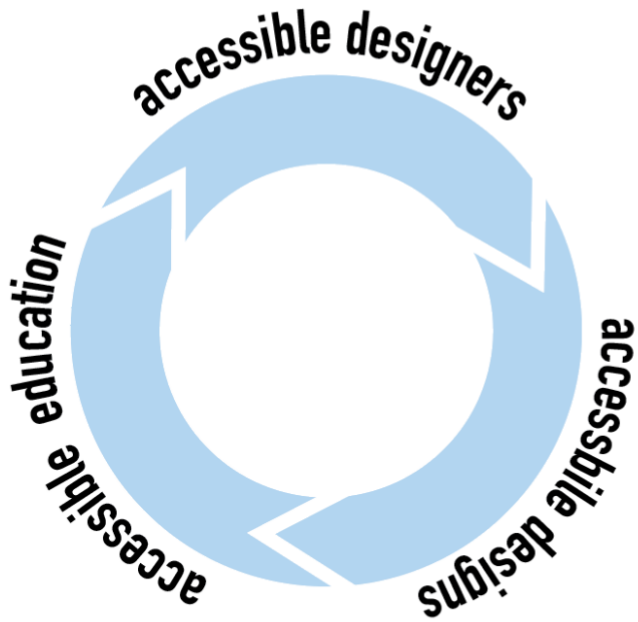


Figure 3: A cycle of inclusion

Lindsay and Cancelliere note that one of the best ways to increase disability confidence is to simply engage with the relevant communities (2018). To that end, design firms of various disciplines might hire more diversely, and capture talent related to the populations they wish to serve. That approach is somewhat precluded by established lack of training for blind and other disabled students that would produce such a cadre of designers. Interrupting the cycle by introducing accessible designs might be effective, but without the expertise of a cadre of disabled design professionals, the granularity of this approach is daunting. The point of intervention must therefore be at the level of education, as all students (irrespective of the abilities) have similar entry points and expertise, and the training can expose student to work on numerous designs. For that reason this study focuses on interrupting the cycle of exclusion in education, employment, and designs, by creating inclusive design education.

1.2 What is Design, and How Can It Be Taught?

A complete exploration of the question “what is design” is beyond the scope of this research project. But the discussion of access to design education and design professions requires some clarification of what is meant by those terms, as they are used in this study.

Definitions of “design” can range from the esoteric to the general. There are theories of design as a specific form of cognition that trace back to Herbert Simon’s 1969 *The Sciences of the Artificial* (Vissier, 2010). Building on Simon, Vissier finds that design is a unique “cognitive activity” (2009, p. 205), while others suggest that, cognitively speaking, design is neither special nor ubiquitous, but something in between, like playing chess (Goel and Pirolli, 1988, p. 4). In *Design Thinking*, Rowe bridges the gap between design as cognition and practice by referring to it as “the complex texture of decision making” (1991, p. 2).

Other than a way of thinking, some definitions of design emphasize that design is a process (Pahl, Beitz, Feldhusen, and Grote, 2007), or that design is the outcome of the process (such as Ralph and Wand, 2009), or they define design as a verb referring to what is done, and what for, in a given discipline (Olson, 2017). Extremely utilitarian definitions, such as “everyone designs who devises courses of action aimed at changing existing situations into preferred ones,” are so haphazard they include anyone who prefers to remove a wrapper from a candy bar rather than swallow it in its packaging (Simon, 1981, p. 130).

This study proposes that design refers to a set of related principles which inform intentional activities, and that “designers” are the people who deploy those principles across a variety of professions. Learning design would therefore, in part, mean learning those principles. Such a definition is somewhat novel because it emphasizes that design is a discipline loosely prescribed by content, where previous definitions delineated it variously as a way of thinking, a process, a set of disciplines, or a verb, and not a body of knowledge. This working definition of design as a constituency of design principles, a body of knowledge that facilitates but is independent of tools and discipline, may be uncommon, but it is not wholly unprecedented.

As early as the 1970s, studies of design activities "as diverse as software design, architectural design, naming and letter-writing," noted that they "appear to have much in common" (Thomas and Carroll, 1979, p. 234). What they have in common is very often their underlying principles. Consider a specific design principle like “iteration” (Lidwell, Holden, and Butler, 2011, p. 142). Iteration was fundamental to both the behaviorist architectural designers of the 1960s (Rowe, 1991, 48), and the Agile designers of the digital era (Vasiliauskas, 2014), despite the different processes, disciplines, and outputs of the two. Iteration is even used to design strategies in warfare, such as the US Air Force’s OODA Loop (observe–orient–decide–act), and business (Chet, 2004).

Another common design principle, “desire lines,” appears in architecture and web design, but also industrial design, marketing, and interior design, and each disciplines uses it own name, including desire paths, heat maps, entry points, or wear marks (Lidwell, et al., p. 76). The principle of “desire lines” is roughly that wear or evidence of use indicates points of interaction, and tell a designer where to intervene. Examples include paths worn into a park’s grass, commonly clicked sequences of buttons on a webpage, or a faded “popcorn” button on a microwave. A tailor who reinforces the worn pads on work gloves, and a automotive design designer who sees wear on cylinder walls are both observing desire lines. Even though their processes, disciplines, and outcomes may be unrelated, their design choices are informed by a common principle.

1.2.2 Design as STEM

Compendiums of design further support that design is defined at a high level by principles, rather than process, output, or disciplines. Notable examples include *The Design of Everyday Things, Revised and Expanded Edition* (Norman, 2013, first published in 1988), *Design Thinking* (1991), *Universal Principles Of Design: 125 Ways To Enhance Usability, Influence Perception, Increase Appeal, Make Better Design Decisions, And Teach Through Design* (Lidwell, Holden, and Butler, 2011), *Universal Methods of Design* (Martin and Hanington, 2012) and *100 Things Every Designer Needs To Know About People* (Weinschenk, 2011). Whether in the title or in the content, each of these are explicitly focused on “the principles of effective design” (Norman, xiii). None of them are discipline or process specific, or mechanically concerned with output (as by tool use). They are self consciously books for a designer of any kind, using principles as their basis.

The authors of these design compendiums are diverse, and not necessarily linked to anything traditionally considered a design field. *Universal Principles Of Design*, for example, is written by a graphic designer, but also an engineer and a project manager (2011). Other authors of design compendiums, like Susan Weinschenk (*100 Things Every Designer Needs to Know About People,* 2011) are psychologists; or mixed scholars of math, computer science, and cognitive psychology, like Don Norman (2013). What defines them as design researchers is not the subject of their disciplines or that discipline's outputs, but their articulation of design as a set of principles. As Richard Buchanan observes, design leverages "the fine arts, the humanities, the social and behavioral sciences, and engineering and the natural sciences--in order to accomplish its work" (Buchanan, 2001, p. 189). Note that many of those fields are STEM related, and some authors collapse elements of STEM and design disciplines completely, claiming the entire purpose of engineering education is to graduate designers (Dym, Agogino, Ozgur, Frey, Leifer, 2005).

1.2.2 Design as Applied Art

But in addition to knowledge of design principles, designers will typically need to apply a given design tool to work some kind of media. For example, an architect might manifest their design with drafting tools, modelling, or generative design programs (Agkathidis, 2016). The tools of design are often the same tools used in the applied arts, including but not limited to sculptures, paintings, graphs, and photography (Vande Zande, 2011, p. 17). By way of example, both sculptors (artists) and architects (designers) will find the skills and tools of drawing and modelling to be useful. Designers and artists both need these tools and media to produce an “outcome,” and “a certain level of skill is needed to shape that medium” (ibid). Practically speaking, then, “the needs of [design] industry closely align with the goals of holistic art education” (Watson, 2015).

Returning to a definition of design: design is as a set of principles derived from findings in science, engineering, fine arts, humanities, and the social sciences (Buchanan, 2001, p. 189), and designers are the people who use those principles in conjunction with a certain skill, tool, or media (Vande Zande), to create their outputs. We present the model in Figure 4 as a visualization of that relationship.

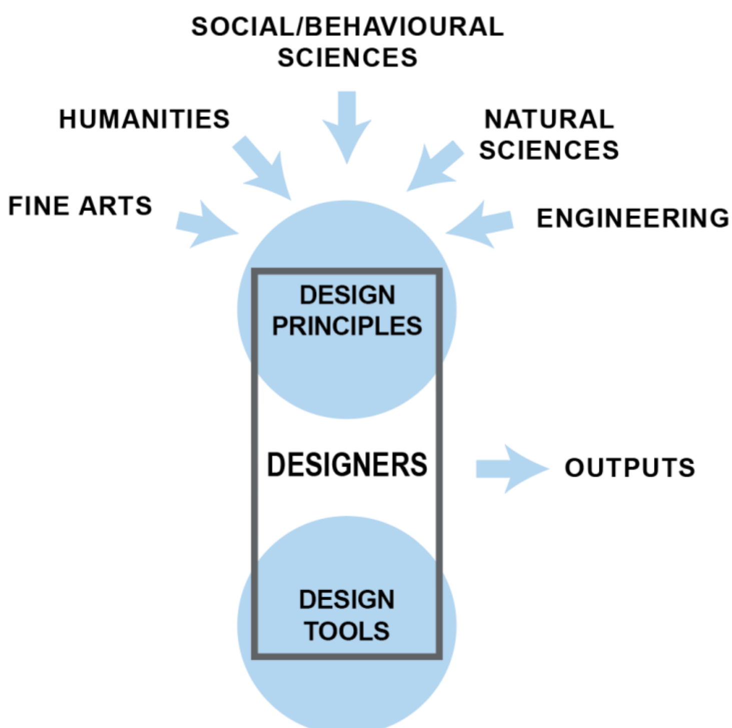


Figure 4: This image shows how the arts and sciences contribute to a pool of knowledge that forms design principles. Designers apply those principles in conjunction with their skill in a given design tool to create outputs

Note that many of the design principles come from Science, Technology, Engineering, and Math (STEM fields), and recall that many design tools are synonymous with those of an applied art[1] (Vande Zande, 2011). Thus designers are positioned at this intersection of STEM and the applied arts.

1.2.1 STEAM education is Design Education

If design principles come from STEM, and design tools are often applied arts, then STEM education alongside applied arts education might also be design education. On this connection of STEM, art, and design education, Bequette and Bequette succinctly observe that "students learn the manipulation of how things work and/or how things look often leads to the creation of purposeful items" (2012 p. 44). That is to say, how things work (the STEM component) and how things look (the art component), come together into something purposeful (the design component).

STEM and the Applied arts have already been combined into a teaching pedagogy known as STEAM, which will be discussed in detail in Chapter 3. But in summary, Henriksen observes that "artful, and real-world connections are at the core of STEAM, and at the core of design too" (2017, p. 8). Bequette and Bequette find that design

[1] According to one university, the applied arts include glassworking, printmaking, ceramics, glass, jewellery, surface design/print, textiles, material art & design, ceramics, fibre, jewellery, jewellery/metalsmithing, textiles, and woodworking (OCADU, 2019). *Applied Arts* magazine describes itself as "explor[ing] the strategic and cultural forces driving creativity in Canada and features the resulting work" and covers "creative advertising, graphic/interactive design, photography, and illustration" (*Applied Arts*, 2019)

thinking could support integration between science and the Arts, and that design thinking has an important role as a bridge within STEAM education (2012). This bridge might look like a simplified version of the previous model, redrawn below Figure 5 It illustrates why an applied art such as woodworking is part of a design education.

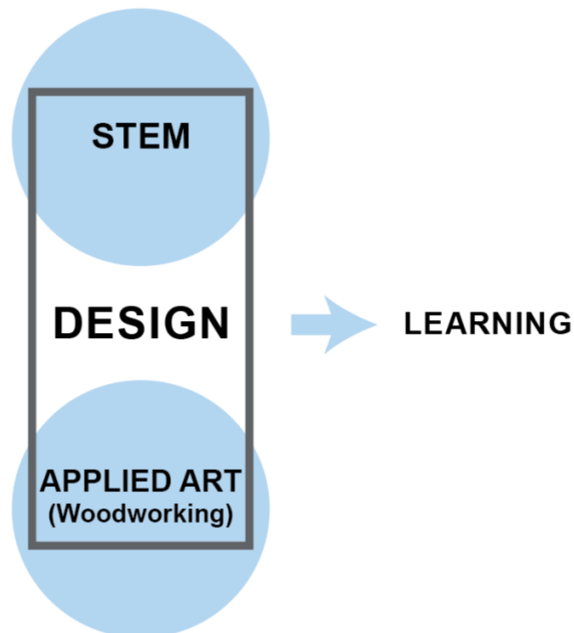


Figure 5: Design draws from the knowledge of STEM and the skill of an art. Consequently STEM education alongside Applied Art education, know as STEAM learning, is Design learning.

1.3 Goal and Research Questions

This study seeks to understand how colleges and universities might offer inclusive education in design related studies through the applied arts (specifically woodworking). The study will investigate:

1) What for-us-by-us instruction methods exist in visually impaired woodshops?

2) To what extent can those for-us-by instruction methods be leveraged by mainstream education to make their workshops inclusive of visually impaired students?
3) What are the benefits and obstacles to inclusive woodworking in mainstream schools?

1.3.1 "For-Us-By-Us" Explained

"For-us-by-us" refers to a strong similarity of the mental models, abilities, and context between the designers and the users, such that the designer and the user might be categorically alike with respect to a number of factors pertinent to the design exercise. In this case, "for-us-by-us" means solutions designed by visually impaired woodworkers, for visually impaired users interested in woodworking. For-us-by-us design can be situated along the recent end of the spectrum of design theories that have, since the late 20th century, increasingly emphasized the importance of the user empowerment and partnership in design processes.

By the 1970s architectural designers began to recognize the need for a clear procedure for producing designs "that could be understood and participated in by all those involved" (Rowe, p. 111). "Participatory Design" was emerging simultaneously in Scandinavia as a method of designing for systems by engaging all stakeholders (Bødker, 1996). In the 1980s software developers started to practice and articulate what would come to be known as "user-centered design," or UCD (Norman, 2013). About the same time, an intersection of UCD with cognitive sciences formalized into design theory the concept of “mental models.” Defined as “a person’s thought process for how something works,” aligning a design with a user’s mental model became synonymous with “positive and useful” design (Weinschenk, 2011 p. 73-74). Early in the 21st century, “Inclusive Design” theorists posited that designers are so intractably biased by their own mental models and abilities, that direct user involvement in the design process was the only way to match a design to user needs (Holmes, 2018 p. 50.)

For-us-by-us design attempts to turn the designer’s bias into a strength, by locating designers whose biasies fit the target users’. This approach is supported by the perception that design teams empathetic to the user are also more effective (Anderson, 2018; Burgstahler, 2013; McGinley and Dong, 2011; Kelley and Kelley, 2015). For-us-by-us designers also have knowledge, training, and skill to shape the design media directly, which end-users often do not. This may advantageously circumvent some of the obstacles to participatory models. For-us-by-us design is not a call for homogenous design teams, rather, it is a call for representational design teams.

1.4 Methodology

For-us-by-us developed courses in applied arts exist to serve the educational needs of disabled students. One example is woodworking for blind and visually impaired students. These courses are offered at institutes for the visually impaired or at government facilities at various levels, and typically facilitated by an entirely blind staff for blind students (for examples see: Iowa Department for the Blind, Hadley Institute for the Blind and Visually Impaired, or the CNIB). There are also online manuals supported and authored by the blind woodworking community at ww4b.org (written by by Larry Martin) and at visionaware.org (written by by Gil Johnston), available in screen reader and audio formats. In this research, we observe a bottom up educational pathway in the form of a woodworking classroom offered by The Lighthouse for the Blind and Visually Impaired. This was a 5 day woodworking course, taught by blind woodworkers, to blind students.

The researcher's choice for observing woodworking sessions was motivated by the connection between design education and applied art education, but also opportunistic. The ubiquitous availability of woodworking courses in Art and Design schools, maker labs, and perhaps home shops all recommend that woodworking has potential for a broad impact. The researchers also have access to OCADU's woodworking programs and faculty, offering opportunities to validate, pilot, or test the findings of the research.

As indicated by the open goals this research is exploratory in nature. The overarching methodology is to use qualitative observation to deepen our understanding of how an applied arts course, specifically woodworking, is delivered for blind students, based on the supposition that STEAM education will address issues of inclusion in design education and practice.

Qualitative data was collected via audio and video recording, note taking, and online surveys. Data was analyzed based on Glaser and Strauss's (2006) Grounded Theory methods, specifically thematic coding. Key and recurring observations in the photos, videos, and interviews were labeled as “codes.” Where enough codes seem to share related concepts, they form “categories.” These categories were considered and generalized into teaching principles, so they might be used broadly. The teaching principles were articulated using the terms and concepts of design principles from Lidwell et al, (2011). This was a deliberate choice to reinforce the connection between design and STEAM. The teaching principles were compiled into a survey for analysis by the blind woodworking instructors who inspired them, along with other blind woodworkers, for validation in a “member check.” In a member check, the researcher's preliminary findings are submitted back to the participants so they asses and comment on its validity (Sandelowski, 2012).

In accordance with grounded theory, locating a phenomenon in context (such as these hypothetical teaching principles in a woodworking course for blind students) requires more than depicting the situation as “a journalist might” (Strauss and Corbin, 1998, p. 182). The account must be “systematic” and “integrated” and specify “the nature of relationships between significant events and phenomena.” Here those warnings are taken into account, and instructors at mainstream universities and college, from multiple design disciplines, will be engaged to assess the feasibility of serving blind woodworking student. In this way the perspectives of multiple concerned parties are engaged from the start, so as to minimize oversights and anticipate as many missing pieces as possible.

In addition to qualitative data, quantitative data can be useful for both verification and generation of a theory developed with Grounded methods (Glaser and Strauss, 2006, p. 18). The recording of the frequency of certain codes is one attempt to introduce a quantitative element introduced here. These quantities might also be useful if conducting replication studies, or for comparison to studies that engage another applied art or population for the same or similar goals.

1.5 Outline

The structure of this research study is as follows:

Chapter 2 presents a brief survey of existing literature and research regarding the importance of inclusion in design education for visually impaired students. Afterwards we will introduce studies that suggest how STEAM education appears to be an especially effective form of inclusive design education for those students, but also what gaps and opportunities those studies present.

Based on those gaps, a study was devised and conducted, and is discussed in Chapter 3. This study recorded the skilled educational approaches of a woodworking class developed by blind woodworkers, for blind woodworking students, through a STEAM lens. The intent was to identify teaching practices and principles that could be deployed in mainstream classrooms to make woodworking and related design knowledge more accessible to blind students everywhere. Chapter 3 presents findings of the study as “teaching principles.”

In Chapter 4, those findings are presented back to the blind woodworking community for their scrutiny. The researchers also interviewed design instructors from the general population, to see what preparations they feel need to be coincident with the inclusion of visually impaired students in their classrooms.

Chapter 5 discusses the implications of the findings from Chapter 3 and 5. Chapter 6 summarize the findings and discuss the opportunities for future work.

Chapter 2: Literature Review

This chapter considers the challenges caused by exclusion in education, and the impact such exclusion has on the designed world. We explore and review related studies that seek to address exclusion in the design sphere through the creation of more inclusive classrooms and opportunities for design education. In considering these attempts at broadening inclusion in design education, it might also clarify where there has been less attention, or gaps, that might form a locus of further investigation.

2.1 Design Inclusion Through Research Methods

“designer becomes the user and the user becomes the designer”

- Holt, p. 161

Chapter 1 discussed the exclusion of visually impaired people from the workforce, and how that results in a cycle of exclusion from designed outputs. Further evidence of exclusion from design outputs for visually impaired and other disabled users exists in the low adoption rates of accessibility aids produced by the accessibility experts (Hurst and Tobias, 2011; Dawe, 2006; Scherer, 1996). As a remedy, many design researchers and practitioners have noted that empathy is the key to effective design teams (Anderson, 2018; Burgstahler, 2013; McGinley and Dong, 2011; Kelley and Kelley, 2015). It follows that design teams who include visually impaired members will be more empathetic to visually impaired users, and will arrive at designs that serve them better.

Approaches to including diverse empaths in the design process do exist. These are variously referred to as human-centred design, user-centred design, ‘participatory’, ‘experiential’, ‘interactive’, ‘open’ or ‘collaborative’ design (see Sanoff, 2000; Menichinelli, n.d.; Scrivener et al., 2000, Anderson, 2018). Generally speaking these methods increase designer-user collaboration through “user centric, empathic design” where the user is welcomed into the design process (Holt, 2011). These methods of introducing empathy may be sound, but in practice the time and money restrictions within a typical design development often result in minimal user engagement (Cassim, 2010). This has especially been the case for visually impaired users participating in participatory design because the expression and communication of design ideas is heavily reliant on visual techniques (Metatla et. al. 2015).

Making design tools accessible to visually impaired users, in a meaningful way, may actually mean making design education accessible to them. If design education were more inclusive, the pool of designers would be more diverse, and more broadly empathic, and capable of reaching previously unreached users.

2.2 Instances of Inclusive Education with STEAM

As defined in 1.2.1, design education is directly related to the combination of STEM and applied arts education, otherwise known as STEAM. STEAM pedagogies are ones that contextualize facts (“what you know”), via an application of STEM knowledge (“what you can do with what you know”) (Hwang and Taylor, 2012, p. 41). The general utility of STEAM pedagogies to introduce concepts in science with the applied arts is noted in Daugherty, 2013; Platz, 2007; Yakman, 2010; Piro, 2010; and Mote, Strelecki, and Johnson, 2014. STEAM is especially valuable for disabled students because it focuses on creativity rather than “correct answers,” and “facilitate[s] and promote[s] the accessibility of STEM learning” by providing alternate means of access (Hwang and Taylor, p. 42).

Alternate access to teaching content is especially important for visually impaired students. This is because a large proportion of STEM education is highly visual in nature, and therefore excludes visually impaired students (Calder, Cohen, Lanzoni, Landry, and Skaff, 2007). For that reason, Calder et al. are developing and testing an audio interface called “PLUMB EXTRA^3” (2007). PLUMB EXTRA^3 applies musical tones as an artist vehicle to make graphical data accessible, and is currently being tested with visually impaired students (ibid, p. 89). The testing is notable as an example of inclusive education and design because testing in done with visually impaired Computer Sciences students - who are both users and designers in the relevant field.

Music has also been explored as a way to teach concepts in mathematics and physics (Amalraj, Sahayaraj, Jothi, Dharmalingam, Rajendran, 2016). Amalraj et al. note that so much of traditional learning in science is visual, and that verbal descriptions of visual ideas are not always ideal or easy to make sense of. Using the violin, they created auditory representations of molecular symmetry that blind students were able to understand (Amalraj et al, p. 114). Perhaps one shortcoming of this study was that the violin playing was not necessarily a direct application of the STEM knowledge, although it did seem to facilitate learning by making the abstract more concrete which perhaps had other applications.

Human Computer Interaction (HCI) is an interdisciplinary field that involves the design of things, and borrows from social sciences, computer science, mathematics, media studies, industrial design, and applied arts. Like other STEM fields HCI relies heavily on visual aids for instruction, which creates a learning barrier for visually impaired students in a field whose products both create and solve issues in accessibility (Chambel, Antunes, Duarte, Carriço, Guimarães, 2007). Chambel et al. sought to address this barrier by creating a web programming curriculum that effectively serve 2 blind students in a class of 200 sighted students (2007). Each blind student was part of a team of student designers on the project, which was to create a multimodal talking book that suited users like them and beyond. The blind students reported that the best aspects of the course were related to executing the project (“what you can do with what you know”, its theme), the contact with a recent type of programming application, cooperation among the team colleagues and usability tests. Sighted students reported gaining accessibility awareness, which supports the theories suggesting the importance of empathic diversity on a design team.

Another STEAM workshop invited visually impaired students to combine technology in the form of electronics with the applied art of weaving, to make e-textiles and “create objects that are meaningful to [the students]” (Giles, Janet and Petre, 2018, p. 1). The study was intended to create ways for blind students to engage with Arduino-style electronics and technology through a hands-on medium (Giles et. al.). It was also an attempt to broaden inclusivity in makerspaces (p. 2). Participants exceeded their own expectation in their ability to create soft circuits through creative, self expressive, and technological means, confirming the effectiveness of hands on STEAM learning in this instance.

Electronic microcontrollers are a common tool of the maker movement, but not the only one. Meissner et al., engaged students with a range of disabilities (one of which was visually impaired) in the context of a makerspace where they applied technology (laser cutters, 3D printers, CAD) with design intent (Meissner, Vines, McLaughlin, Nappey, Maksimova, Peter Wright, 2017). A blind student used a drawing program and a laser cutter to create “five beautiful artefacts” (ibid. p. 1060.) She was impressed with how easy it was, and emphasized how the technology *helped* her create her own designs (ibid). Participants noted their maker skills would be valuable in self-directed accessibility hacks (1062). Similar manifestations of DIY for accessibility has in fact formed a community of accessibility designers, as noted by Tobias and Hurst, 2011.

Certain tactile teaching implements have been shown to be effective in STEM application. One such implement called a Belcastro rod has “grooves and dimples that distinguish them from one another” which a user counts using their finger (figure 6, Salvo, 2003). It has been shown to be very effective in teaching mathematical concepts to blind students (Belcastro, 1993). A similar tactile ruler, called a click rule (Figure 7), is sold to visually impaired makers, such as woodworkers, to take measurements and perform mathematical operations with fractions. The click rule was observed in use in Chapter 3.

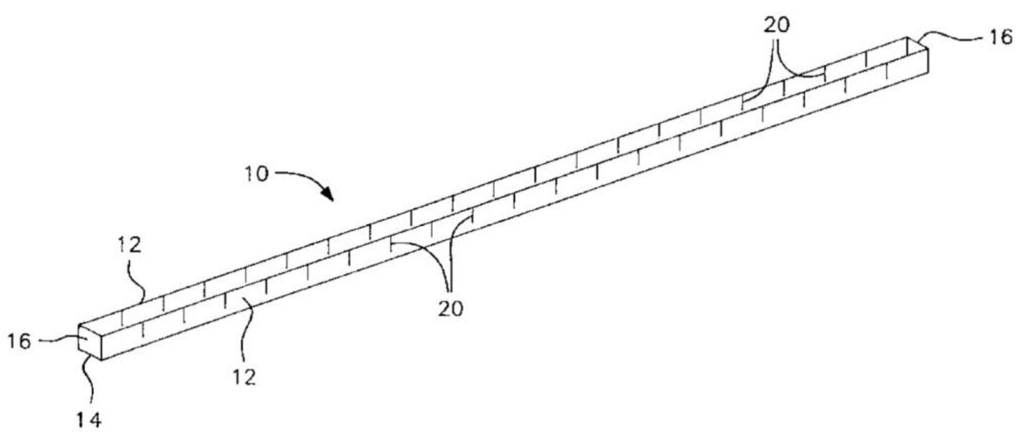


Figure 6: A patent image of a Belcastro rod, a math teaching tool for visually impaired students.

Figure 7: A click rule

Expertise in the applied arts, specifically woodworking, among members of the visually impaired community is not a subject of research, and more a subject of established practice. The refinement and dispersion of visually impaired woodworkers should not be underestimated. Literature on the operation of tools and techniques blind woodworkers are documented by expert woodworkers at ww4b.org (2019) and www.visionaware.org (2019). Practicing blind woodworkers known in the public sphere are Larry Martin (ww4b.org), Gil Johnston (Barnidge, 2013), Clay Gurganis (Pusey, 2008), and George Wurtzel (Tillotson, 2014), among others.

2.3 Gaps and Opportunities

Woodworking is an applied art that requires mathematical calculations to cut angles and ensure fit, it suggests scientific knowledge of wood properties (grain structure, density, materials selection), it uses technology that is simple, like saws, to the more advanced, like CnC, and has an engineering component in its planning and design phases. On considering this, the study discussed in Chapter 3 is a clear opportunity for STEAM learning where “what you know” becomes “what you can do with what you know.” Further, it addresses gaps in existing research, namely the lack of individualized solutions. Where most research has been created by mainstream instructors, and their lessons delivered in a top down fashion, this study of blind woodworkers is a bottom up, for-us-by-us STEAM workshop.

Studies discussed in Chapter 2.2 were developed by educators to supplement visually dominant STEM classrooms with non-visual delivery, through applied arts including music, drawing, measuring, electronics, weaving, programming, or participating in an active design role as part of a design team. These studies have a limitation in that they were mostly administered in controlled settings, by sighted or non-disabled instructors (although a visually impaired HCI instructor was consulted in, but did not conduct the study reported by Chambel et. al., 2007). Further, the STEAM pedagogies above are designed by sighted instructors for visually impaired students, which means they are inherently limited in empathic potential and effectiveness.

Studies in this area have necessarily focused on the student and their needs. But less has been discussed concerning how design and STEAM lessons for visually impaired students can be integrated into mainstream visual classrooms. More research needs to be done into the needs and concerns of instructors, as serving student needs manifests, incidentally, as serving instructors’ needs in many cases. For those reasons this study will interview mainstream instructors to asses their concerns and needs, specific to serving visually impaired students, and what obstacles they might face in making their STEM or applied arts classrooms accessible.

Another barrier that impacts visually impaired students' access in traditional STEM classrooms is lack of individualized supports (Dunn et. al, 2012). "Lack of individualized supports" refers to the customizability of the lessons formats for a specific student's needs. With STEAM pedagogy there are in theory as many individual support options are there are applied arts. A student can select from a range of applied arts and find one that fits them individually, and earn STEAM that way.

Existing approaches to making STEAM accessible do not maximize that potential for customization, because they have so far been devised, incidentally, around what the *instructors* are good at. For example, HCI researchers create STEAM through HCI (Chambel et. al., 2007) and musically apt professors developed STEAM learning through music (Amalraj et al., 2016). Admittedly, the researchers in this study have an interest in woodworking, and they have chosen to create STEAM through woodworking.

This study acknowledges the drawbacks of that top-down apporach. We seek to limite it in two ways. First, the visually impaired students in this STEAM woodworking classroom have *chosen* woodworking, before the researchers had suggested it. It was the individual student's own interest that drew them to this specific applied art (out of the options available). Second is the for-us-by-us methodology. The instructors in this research are visually impaired, potentially more empathetic in their classroom design. It is entirely developed by, taught and delivered too, visually impaired users. Unlike existing accessible STEAM research classrooms, this one is pre-existing, successful, for-us-by us STEAM workshop, ethically designed and refined through years of teaching experience.

Chapter 3: Study

There is no cloistered calm of study here;
The clang of hammer and the whine of saw,
The spun vise gripping metal in its jaw,
Are making music, pleasant to the ear.
No stock of books and graphs and other gear
Is needed for this classroom's busy law.

- Shop Class, 1934

This study considers that woodworking is a locus around which design education can occur for visually impaired students. That supposition is embedded in STEAM pedagogies (woodworking as an applied art), the generic design hypothesis (that design cognition is stimulated by many activities), and the existing DIY solutions already being designed by woodworkers and other makers. Design education is especially important for visually impaired students because they have noted that lack of training options has limited their career success, and because design firms can greatly benefit from the addition of diverse, empathetic designers. The study seeks to identify and articulate woodshop best practices and outcomes, so that colleges and universities might offer enrollment support for visually impaired students in design classrooms. The primary source of information for blind woodworking best practices is the for-us-by us blind woodworking course offered by Lighthouse for the Blind and Visually Impaired at Enchanted Hills, and blind woodworkers.

3.1 Study Outline

Data for this study was collected in three phases.

1. In situ data collection with a woodworking workshop for blind students (chapter 3)
2. Member check interview and survey with blind woodworkers (chapter 4)
3. Interviews with sighted woodshop and design instructors at public universities and colleges (chapter 5)

The primary researcher attended a 5-day woodworking course for blind students at Enchanted Hills. The course was documented with notes (Appendix E), photography, and video recordings (Appendix B). The approach was primarily observational and hands off. In some instances, clarification was sought directly, by verbally asking a question about a specific method or the motivation behind it. For example, the researcher asked one instructor when they prepared the classroom, how they prepared it, and how long it took. The researcher slept on site at the camp, where he ate meals with the camp staff and students. Conversations occurring with the instructors and students in this context are not utilized for the research, and were not recorded in any way.

The researcher did not participate in the workshop activities directly, but did operate the drill press, lathe, and chop saw under the guidance of an instructor. On each of these occasions one instructor, unprompted, encouraged the researcher to use a sleep shade (blindfold) to simulate visual impairment. It should be noted that “experience simulation” of blindness is controversial. This is partly because sighted users engaged in blindness simulation afterwards judge blind users as less capable of work and independent living

(Silverman, Gwinn, Van Boven, 2014). Because the researcher could plainly perceive the expert workmanship of the instructors all around him, and the capability of the students (who were skilled piano tuners, luthiers, business people, and medical professionals) he was in no in danger of such misjudgements. Further, the expert guidance of the instructors mitigated the sighted user's potential for failure, and consequent the erroneous judgements about ability. Ultimately the question of blindness simulation and other perspective taking exercises should always be approached with sensitivity to context and participants.

Data gathered during that course was coded and interpreted into a set of potential teaching principles. Those potential principles were inserted into a survey (created on Google Forms), which was submitted back to the community of blind woodworking instructors for their validation and refinement. The returned surveys are the second instance of data collection. For the final stage of data collection, researchers interviewed sighted instructors at mainstream colleges and universities to anticipate how the teaching principles might be deployed in the context of a public academy. During these unstructured interviews, data was recorded with notes, reproduced in Appendix D.

The data collected during phases 1 and 2 was coded, and related codes were organized into categories. Those categories evolved into the recommended teaching principles, and first mentions in the study description will be bolded. The categories closely resemble design principles from Lidwell et al. 2004, for example, *chunking,* *modularity,* or *progressive disclosure*. This language was consciously chosen to reinforce Vissier's theory of "generic design" cognition and to leverage the design community's familiarity with those understood concepts. A complete list of codes are in the appendix (see appendix A), along with links to any images or videos that support them.

Data collected during interview with instructors at OCADU will be introduced in the Chapter 5. Instructors were invited to voice their concern about having blind students in their workshop, predict pain points, what resources they might need, and ask their own questions.

3.2 Study Site Description

The woodworking shop was hosted by Lighthouse for the Blind and Visually Impaired at their Enchanted Hills Camp on Mt. Veeder in Napa Valley, California. The 7 students stayed on site for 6 nights of the course. The fee was $300 per student, which included quality food, lodging, and all building materials. All instructors were blind, and there were no sighted staff in the workshop.

The woodshop at the study site in Enchanted Hills is a well equipped workshop with a full suite of woodworking tools (Figure 8, Figure 9). No assistive devices were used. The only a-typical tools may have been the range of measuring devices, which included talking levels, talking tape measures, and the click-rule (a tactile ruler.) Detailed instructions on how to use the click rule, and how blind woodworkers operate tools, are available in manuals at ww4b.org (written by Larry Martin) and at visionaware.org (written by Gil Johnston).

Figure 8: Interior of the woodshop taken from just inside the front door.

Figure 9: Interior of the woodshop taken from the rear doors.

Similar to sighted woodworkers, the community of blind woodworkers leave the use of tool guards and safety devices to personal preference. At this workshop, manufacturer installed guards were left intact. For example, the plastic guard on the compound miter was present. The table saw was not a SawStop, and no writhing knife or blade guard was present.

The skill of the instructors as woodworkers should be regarded as expert. The primary instructor, George Wurtzel, owned and operated a cabinet making business, managed a production facility, and has been featured on the cover of trade journals (Figure 10).

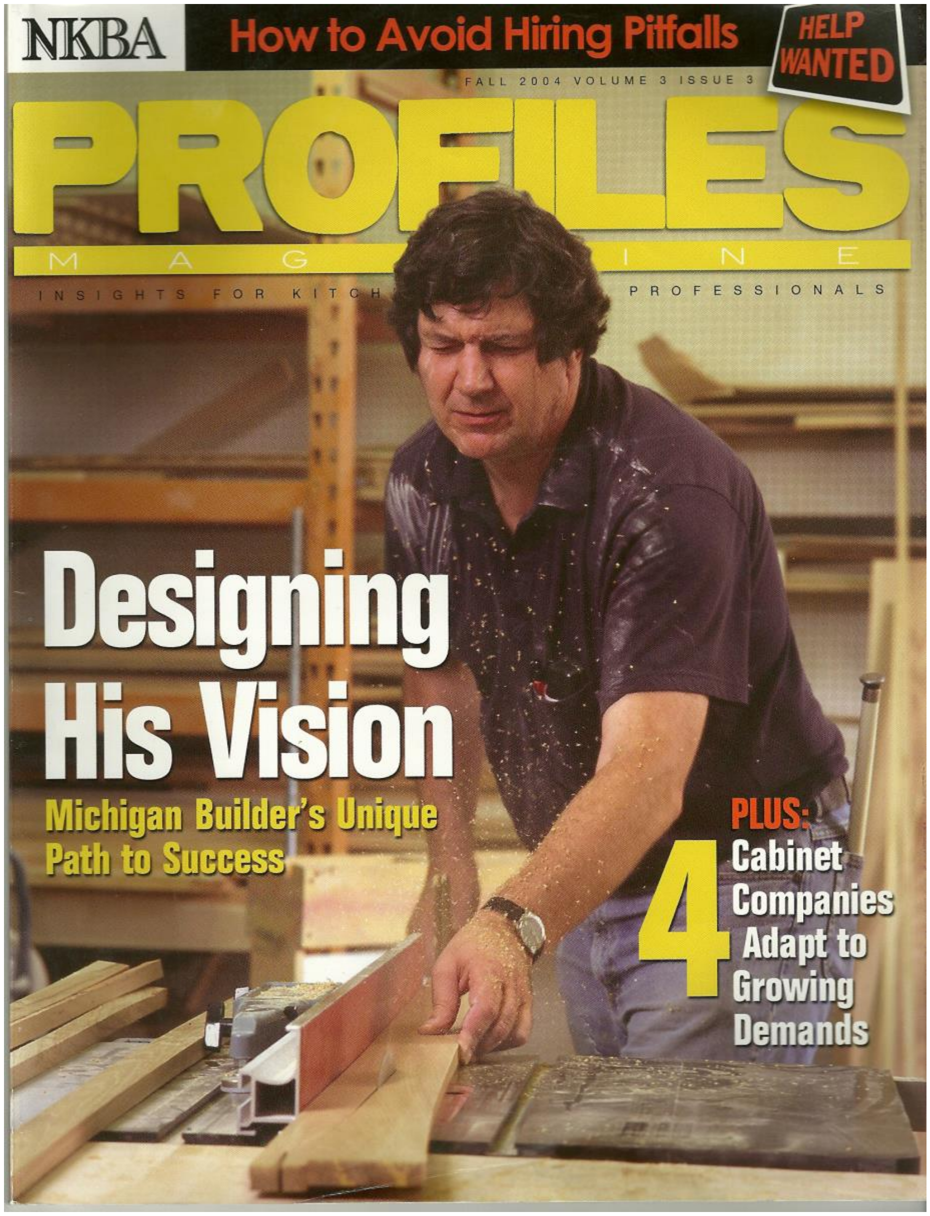


Figure 10: Cover of Profiles Magazine featuring George Wurztel. (Hitti, 2004).

George was completely blind by the age of 20, and never had enough vision to see text on a page. He has over 40 years of professional woodworking and teaching experience, and maintains a practice as a woodworker and artist as his primary income (Hitti, 2004). George was joined by Jeff Thompson, who runs the “Blind Abilities Podcast” and has been a woodworking instructor and community leader for over a decade and across

America. Bryan, another instructor, demonstrated expert knowledge and ability commensurate with his experience.

3.3 Woodshop Students

Students participating in the woodworking course were made aware of the purpose of this study, and ascended to their potential identification in the photography, video, and notes presented in this study with signed disclosure agreements. Students were aged 30-60, all legally blind, and attending from as nearby as California, and as far as Quebec, Michigan, and Georgia. Although the course was offered as a “beginner” course, the students had varying levels of knowledge. Some were returning for their second time, some had previous experience as woodworkers, and some planned to stay at camp another week to attend the “advanced” course for their second time. Many students knew each other from previous years, and from their activities in the wider community.

3.3.1 Safety Training

It is common in workshops, labs, and makerspaces to require students to take some form of safety training. Typically this includes a study component verified by a written or online quiz. The OCADU quiz is provided online in their student learning portal. The quiz requires that students memorize safety distances from blades, shop etiquette, tool storage, and orientation with the location of safety shut-off switches. The workshop in this study did not require any form of regimented safety training comparable with mainstream institutions. No injuries, major or minor, occurred over the 5 day workshop.

On the first day of the course instructors provided general cautions about the extreme danger of tools, including the violence and rapidity with which they can remove limbs. Students were told to tie their hair back, and not to wear loose clothing or bracelets. Respect for the tools was emphasized, but also that careful and intelligent tool use can makes safety entirely possible. Additional safety training was provided on a per tool basis. For instance when being show the disc sander, it was explained that you cannot safely press a workpiece into both sides at once, as the rotation will send the piece into the air. In another case a student being shown a large router was cautioned about the kickback when moving with or against its rotation (Figure 11).

Figure 11: An instructor demonstrating the safe operation of a router, in particular the kickback behaviour when moving with or against the rotation of the bit.

3.4 Overview of a For-Us-By-Us Woodshop project

Students arrived at the camp and gathered to meet for the first time before dinner of day 1. A meet and greet occurred between students and instructors. The instructors also introduced the project (candy dispenser), referred to as “the product” (Figure 12) and briefly described how it would be made. A completed candy dispenser was passed around for students to feel.

Figure 12: The candy dispenser and its component hierarchy

The procedure to create the product was as follows. Steps 1 - 5 had to be completed first, but the remaining steps could and did occur in various orders:

1) Rough planks of wood were planed down to a thickness of just slightly over ¾ of an inch. Thickness was measured by comparison to gauge blocks, click rule, or know correct pieces by feel.
2) One edge of the thickened plank was jointer square on an 8 inch jointer.
3) Both sides were sanded smooth on a drum sander.
4) The thickened, square, and smooth boards were ripped on a table saw to a width of about 3-¾ inches so they became “sized-up” boards.
5) The sized-up boards were cut to 5 inch lengths on the chop saw. These became the blanks for the body sections.
6) Using the drill press with a hole saw, a hole was drilled into the centre of the top body piece, and another hole was drilled offset from centre on the middle body piece
7) Using another drill press a ¼ hole was drilled into the middle of the bottom layer along the top edge.
8) The top section was placed into a vice and the hole from step 6 beveled with a router
9) The middle section was placed on a router table the the hole from step 6 received a bevel
10) The plug from step 6 wss turned on a lathe into a wheel
11) All 3 body layers were glued together together and clamped
12) Once dry, the body was sanded on a drum sander and by hand
13) Edges of the glued together body were rounded over with a router
14) Apply oil finish to body and wheel
15) ¼ inch aluminum rod was cut into 1 inch long pegs with hacksaw
16) Glue ¼ aluminum peg into bottom section so that is becomes an axle for the wheel in the middle
17) Glue mason jar lid-ring into top section

18) Fill mason jar with candy and screw into li

3.5 Results: Teaching Principles

The purpose of attending the blind woodworking course was to identify four-us-by-us developed teaching practices that could be used by mainstream colleges and universities to offer design education to visually impaired students through the applied art of woodworking. After coding the data collected from observing woodworking class, evidence supporting 10 Teaching Principles emerged. They are presented roughly in the order that examples emerged incidental to the order of the manufacture process in Chapter 3.4.

It is likely that these teaching principals are familiar to many instructors, particularly in the design fields from which their language is appropriated. However, the character of their specific deployment differs in a visually impaired context. Key differentiations are summarized in the descriptions below. There cannot be any strict ranking of importance across the teaching principles, because in practice such a ranking would be project dependant. In this project, for example, the hierarchy principle was a substitute for written plans. A plan was critical because student work had to fit together. For a project with a less directed and coordinated outcomes, a hierarchical schema may be significantly less important. A few principles suggest they are more universal, and those will be mentioned below. Thus the principles are listed roughly in the order which they were recognized during observation and subsequent coding, although even that is not entirely possible because principles arose at all times during the workshop.

Summary of Ten Principles Visually Impaired Woodworking Instruction:

1. **Hierarchy**
   tree or nesting structures that facilitate comprehension of multi-level systems and the their composition

2. **Confirmation**
   preventing unintended actions by requiring verification, or providing verification

3. **Modularity**
   A project is broken down into interchangeable components

4. **Chunking**
   breaking down large tasks into smaller tasks

5. **Constraint**
   limiting the actions available on a system

6. **Flexibility-Useability Tradeoff**
   flexible systems are less usable, less usable systems are more flexible

7. **Iteration**
   repeating operations until desired outcome is achieved, or guess and check

8. **Piloting**
   testing a system or lesson plan before use

9. **Progressive Disclosure**
   proving layers of information at the speed they can be learned, and diffusing information in helpful ways

10. **Control**
    the level of user control should be consistent and supportive of ability: maximising potential for students growth but limiting potential for injurious failure

What follows is an explanation of each teaching principal and a description of just one example of how it was observed in teaching practice. For videos demonstrating the principles refer to Appendix B. For a complete list of codes and supporting images and videos, refer to Appendix A.

3.5.1 Hierarchy

Many woodworkers work from plans. Plans are printed onto paper, and often cut out and traced onto the wood. For non-visual woodworkers, these sorts of plans are not helpful. On the first day of class the instructor gave a detailed description of the product. Instead of drawings or blueprints, the project was broken down into a hierarchy of components by verbal and tactile means. Components were described in terms of how they fit and function together to make the product, and how they might be manufactured from one piece.

Projects with clear or flowing hierarchies can be easier to remember. Think about components and how they fit together, and if it is random or if it can be mapped on to a structure that can be kept in memory. Maybe it has components that map onto a hierarchy that already parallels a mental model the student has internalized. This might be a project with a main section or “body,” parts that stick out like “arms,” and a top like a “head.” And instead of a visual diagram, have a completed version of the project side by side with an exploded version.

The exploded version should let students manipulate the modular components and learn their shapes. A clear hierarchy that has clear relationships from one piece to another can be easier to commit to memory. Students can refer to the “exploded tactile plans” if they need too, but being able to construct and store a mental image of the completed object, its parts, and how they fit together is useful.

An ideal situation occurs when not only the project’s modular components have a clear hierarchy in relation to the complete project, but when their relationship to the rough lumber from which they are machined is hierarchical as well. In Figure 13 you can see how the hierarchical nesting of pieces minimizes the dimensions that need to be memorized. All of the project’s wooden parts can be cut from one piece of wood. It requires only a single thickness, one width measurement, one length measurement, and one hole saw diameter. Yet it produces many distinct pieces that all fit together. Note also that the pieces have helpful relationships: the three sections are identical to a point, the two holes are the same size, and must naturally be, so that the plug from one fits into another.

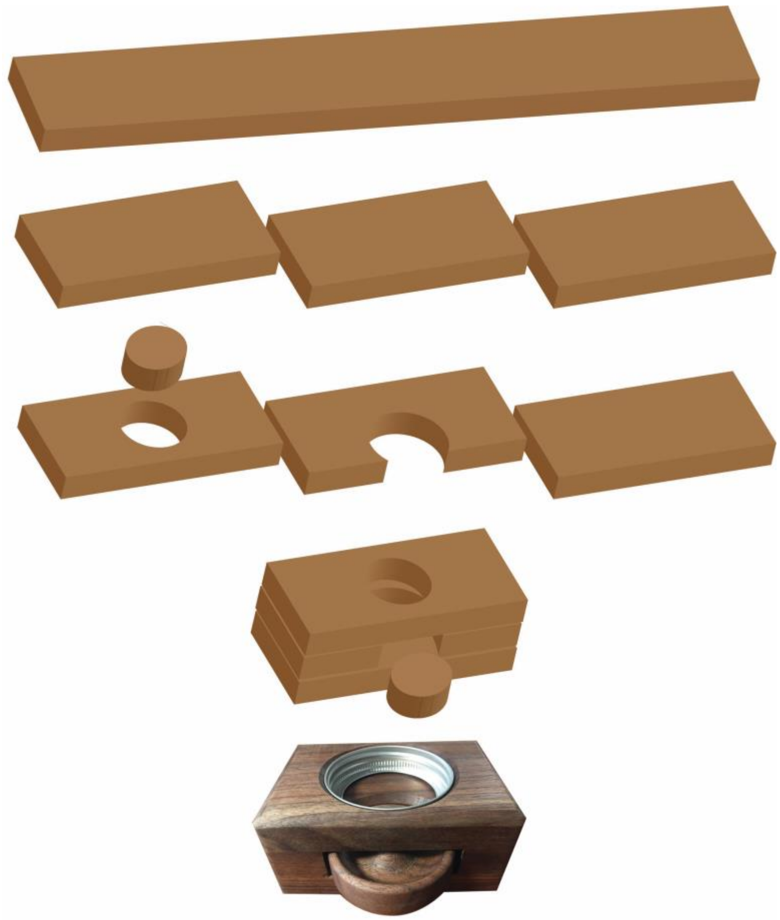


Figure 13: A visualization of the exploded components of a wooden candy dispenser, showing the hierarchy of the pieces descending from one board.

The absolute measurements are non-critical. They do need to be reference from plans or memorized. Each piece only matters in relation to the other, but since they all descend hierarchically from the same piece, they retain many necessary dimensional aspects naturally. For example, the thickness of the wheel must be equal to the thickness of the centre part, but it always will be because it descends from the same "parent" board.

3.5.2 Confirmation

Confirmations prevent unintended actions by requiring verification, or providing verification, of a behaviour. Most people are familiar with confirmation in UX design. An example is a pop-up window that asks, “are you sure you want to delete this file”? In woodworking, confirmations have a safety role, generally asking “are you sure you want to put your body part there”? or “are you sure it is ok turn on the machine now”? Woodworkers use visual and audio confirmation, such as the blur and whir of a spinning saw blade. Woodworkers also use tactile confirmations, such as safety switches that require two movements.

Blind woodworkers identify additional tactile confirmations that might not be obvious to sighted woodworkers. These include lines incidental to a tool’s manufacture, such as the joining of two surfaces in a platen, or the knurling on one button, but not another, or repositionable confirmations like a magnetic feather board. These confirmations might indicate a safe or unsafe area, the function of something, or when to change grip. Tactile confirmations should be explored, identified, and explained by an instructor before tool use, for safety purposes. Encourage students to develop their own.

The process of bringing the rough wood to size require use of the the planer and the table saw. Instructors demonstrated to students how those tools make tactile **confirmation “**requests” with their shape and sound. Confirmations included tactile location of safety zones, verbal mentions of tool being turned on, it sound, and set up of the workpiece. In Figure 14, an instructor is placing a student’s hand on the exact spot that indicates “you are getting close to the blade” and the feather board meant “do not move your hand any further forward.” A video of this practice is available in Appendix B.

Figure 14: A teacher is placing a student’s hand at a confirmation point on the table saw. The block of wood in the foreground is a magnetic feather board.

The difference between the finish of the planer’s table and its table extension is visible in Figure 15. This difference was just as obvious tactically as it is visually, and when the line between the platens was perceived by feel, it became another safety confirmation. Figure 16 shows a safety “on” switch that is physically distinct from the other switches on the tool and requires multiple actions to turn it on. Note also that the operating levers on the tool in Figure 16 are similar, but still distinguishable by feel. Operation interfaces that are not discreet, such as a digital buttons or dials without hard stops, provide no confirmation and should be avoided.

Figure 15: The surface where the table extension meets the planer table was a tactile indication to an operator that their hand is too close to the blades and the infeed slot.

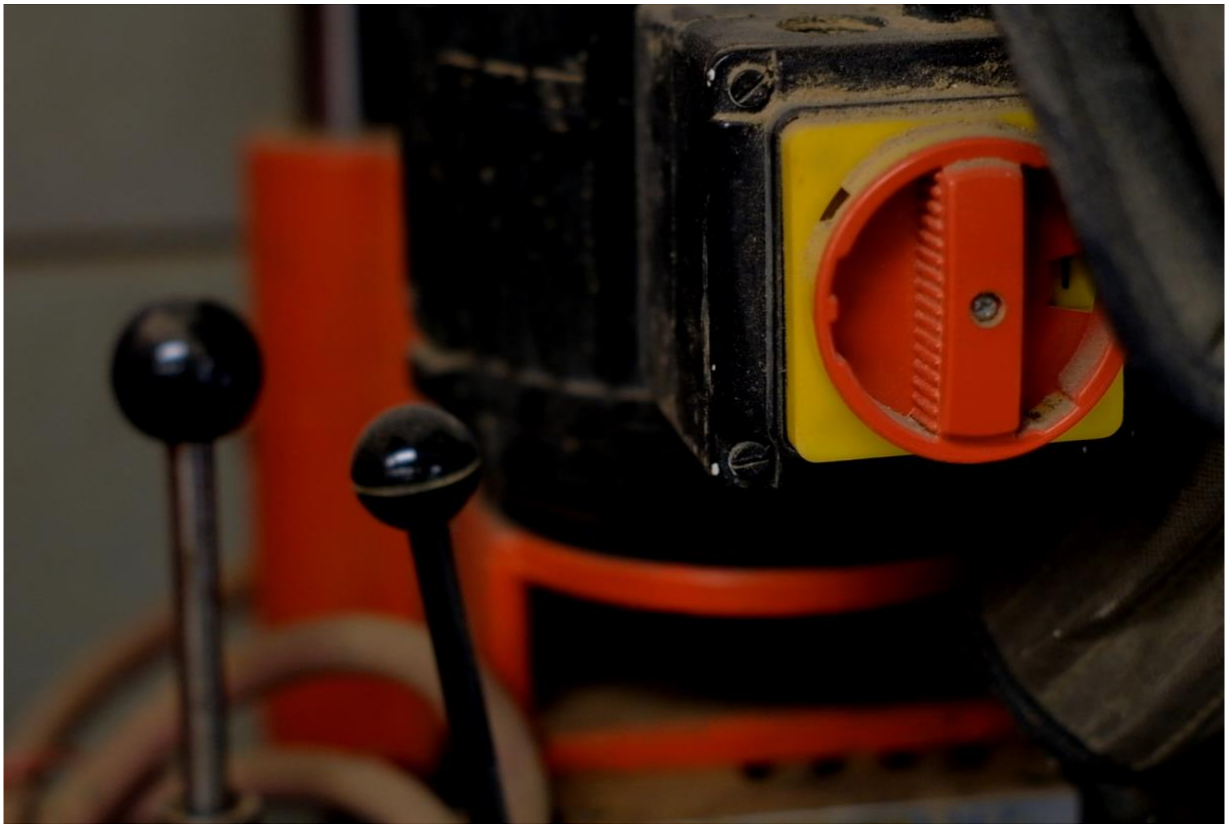


Figure 16: A safety power switch requires the operator to perform extra actions to turn a machine on. Note that off/on switch is perceptibly different from the operation switches, which are different from each other.

3.5.3 Modularity

Modularity refers to interchangeability of individual parts across like-products. For example, the wheels and doors from one 1966 Ford Mustang will fit any other 1966 Ford Mustang. Those wheels and doors are said to be modular parts. Similarly, the middle part from one candy dispenser would fit any other, as would the jar, wheel, and so on. Modularity is not strictly necessary, but it is beneficial enough to strongly consider for novice or mixed ability learners. Arguably, it allows for a more complex product to be made because modular projects are predictable and therefore pilotable. It also encouraged teamwork by creating a shared goal, as students made stacks of modular components before assembling them.

In groups of mixed ability students it can distribute the manufacture of every product across the group, so that every student will have the access to the necessary components to complete the product. A student who wants to focus on one modular part can do so, and can avoid modular parts that requires tools they are uncomfortable with. When a group of students works as a team to produce an undefined number of projects, modularity can let students work at their own pace. One student might make more parts than another, but they all go into a stack, so it doesn't really matter. Modularity can lets students work at work at their own pace. In the end, there will be enough modular parts if everyone works together.

Once the body sections were cut from the sized-up wood, the remaining steps (from 6 onward) could be done in a variable order. This was possible because of the **modularity** of the components. As long as all the necessary components were used, they could always be combined into a product, without regard for who make which individual component. Figure 17 shows stacks of modular parts, made by all students and in no particular order, and Figure 18 shows them glued together. Modularity also meant that if a single student had consistently made an error, or was unable to perfect a certain operation, they could still realize a completed product from the extra modules.

Figure 17: Stacks of modular components. Clockwise from top is the bottom of the candy dispenser body, the top, and the middle.

Figure 18: A row of 7 bodies, assembled from modular parts and clamped during glue-up. More modular parts are visible in the background.

3.5.4 Chunking

Looking at a finished piece of woodwork, or a finished anything, it isn't always clear how it got made. But on closer inspection, many maker projects are really just comprised of the outputs of many small tasks. We call those tasks "chunks." Squaring an edge is a small task. Ripping to width along the squared edge a is a small task. But after those tasks or chunks, even though no modular component or clear progress has been made, you are getting closer to a completed project. Chunking happens naturally whenever we do things in steps. But self-conscious awareness of chunking demystifies a process and makes projects approachable and repeatable for students.

Chunking is important when visual plans are not an option. A novice student can be shown each chunk of work, and allowed to repeat it until it is memorized, without the cognitive load of memorizing every step in an entire project. An advanced student familiar with common chunks of work (such as those in the sizing up process) can refer to the example hierarchy of the exploded components, the “plans,” and infer what chunks of work are necessary to make each component. Chunking is also important because it facilitates progressive disclosure, by having the option for distinct units of learning.

Chunks of work are also transferable. In woodworking, the sizing up process is made up of chunks of work common too many projects, so a student who learns the chunks of work involved in sizing up wood has learned the first steps to practically any other project. Another useful chunk of work is joinery, including dovetails, dowelling, dados, or lap joints (Figure 19). Joinery is foundational to many woodworking projects. A student who learns the "chunks" of work involved in joinery can then transfer that knowledge to nearly any other woodworking project. They can feel a box, a drawer, a cabinet, a or dresser's edge and say "I know how to do this."

Figure 19: Examples of joinery. The box on the left is joined with dovetails, the object on the right uses a complex joint the author is unable to identify.

Chunks in this study classroom were small enough to complete in one sitting, and hold in short term memory (less than 10 minutes, and usually shorter, sometimes 30 seconds). In Figure 20 the chunk of work being completed on the modular bottom of the body is that a hole is being drilled to accept the pin upon which the wheel spins. The chunk of work has a clear beginning (no hole) and a clear ending (has a hole). Once that chunk of work is completed, another one awaits.

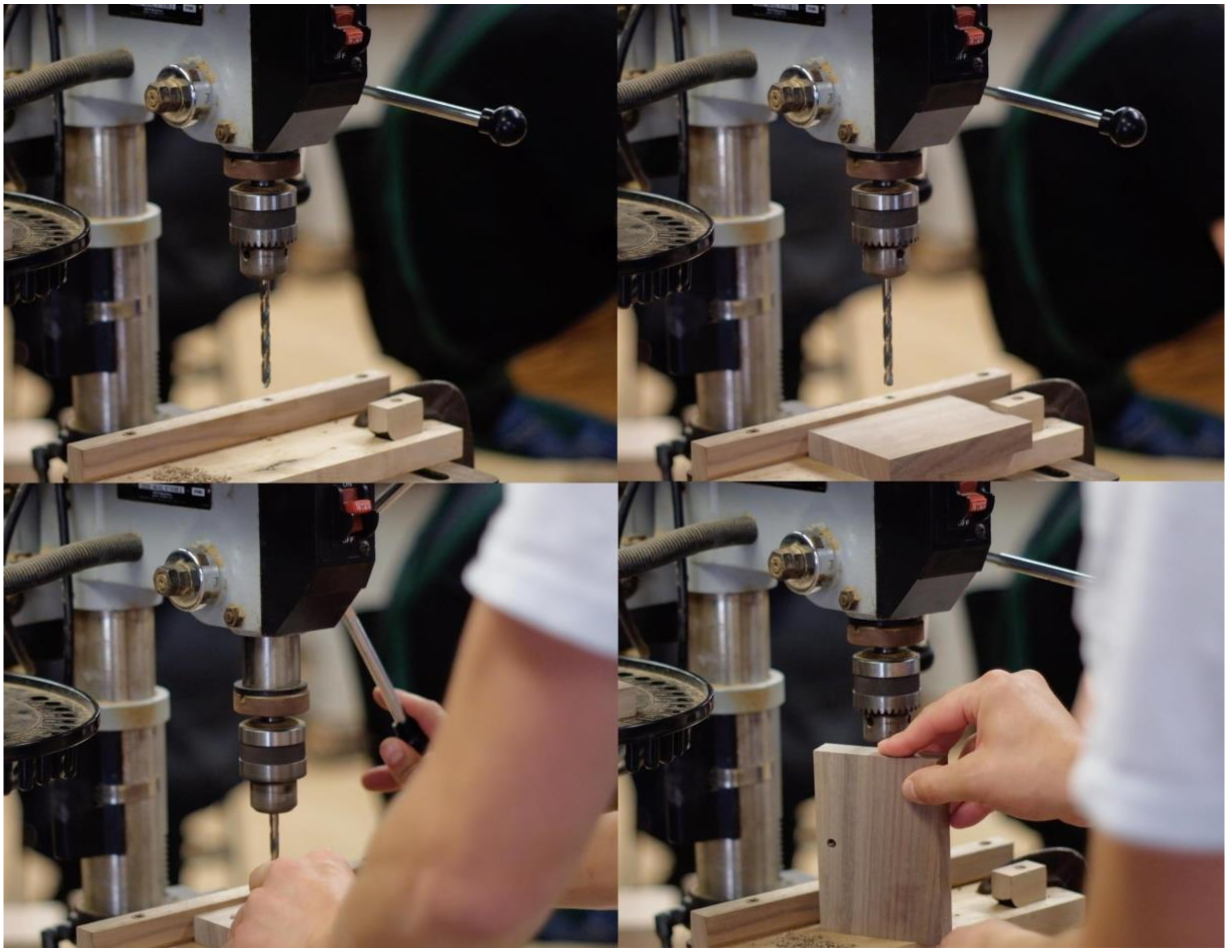


Figure 20: A chunk of work can be a simple as drilling a hole.

3.5.5 Constraints

A track constrains a train onto a pre-determined path. That is also how it can move quickly and safety to a predictable destination. Woodworkers use also use “tracks” that move or hold tools or workpieces in intended paths. These constraints include clamps and stops, and have names like jigs, and fences. Whatever they are called, constraints fill the role of guiding or holding a workpiece in place.

Constraint is helpful for visually impaired woodworkers for the same reason it is helpful for sighted woodworkers: it increase predictability and safety. Blind woodworkers have perfected the application of jigs, and they often remark that sighted woodworkers are more likely to injure themselves because they do not take the proper care in setting up constraints. Blind woodworkers theorize that this is because a sighted woodworker is more likely to rely on their sight rather than adequate preparation.

Constraints also provide tactile registration, as by a physical stop, rather than visual, as by a measuring tape, and are therefore preferred by visually impaired woodworkers. You can see in this simple drill press jig that the workpiece is pressed against a back and a side “stop,” so that it registers correctly underneath the drill bit (Figure 21). In order to prepare jigs and constraints, woodworkers should learn piloting and iteration. But a simple explanation of preparing a constraint is measuring the expected size of a cut, setting up the constraint (perhaps a fence, or a stop), making the cut into a piece of scrap, checking it against the intended measurement, and then adjusting as necessary. Once the constraint is correct, an indefinite amount of accurate cuts can be made. See Appendix B for complete video footage of a drill press jig.

Figure 21: This simple jig secured a workpiece such that the hole saw cut a hole in the correct spot.

An unseen stop, separate from the jig and part of the drill press stops the quill from dropping down to far in the z-axis. Other forms of constraints include saw fences and guide bearings. The device in Figure 22 is a miter fence, which is tool for cutting angles. It works by constraining the workpiece path along a pre-set angle and trajectory.

Figure 22: A miter fence for a table saw. The fence sits in a track that slides parallel to the saw blade. The fence is constrained in the track, but can be angled relative to the blade so that it can cut from 0 to 90 degrees while safety holding the workpiece.

3.5.6 Flexibility-Useability tradeoff

A CnC router seems like a highly flexible tool. It can cut any shape you might imagine. But is it useable? Is its function obvious, how much training does it require to load a file, or to design a file? Can it be explored by a novice? Can a visually impaired user easily operate the visual design programs that drive it? The flexibility of a CnC comes at a cost of how usable it is.

Large multi-tools, like a combination jointer, planer, shaper, table saw, should be avoided when teaching groups of visually impaired students. In consultation for this webpage, one blind woodworker called them boat anchors. For one, the set up and breakdown times are disengaging for anyone who cannot watch. The primary benefit of a multi-tool is that you only need one machine. But when all of the work takes place on one machine, students must stand in line and wait for their turn, which is not helpful for non-visual learners. Another problem is that flexible tools are hard to use, because switching them between uses can throw them out of calibration. This causes boredom as the machine is reset.

The biggest problem with highly flexible tools is that their flexibility tends to obscure their purpose, which impacts usability. For example, the Felder CF 731 (Figure 23) is a “combo tool” which can be converted between sliding table saw, jointer/shaper, and mortisor. The flexibility to change between jointer and table saw comes with a usability price - set up and breakdown is complex, it takes time, could have to be done more than once while students wait. Having two seperate tools - albeit each being less flexible - was deemed the more usable approach.

Figure 23: A Felder CF 731

In the next image is a chop saw (Figure 24). The function is easy to perceive by sight or feel. The blade is obvious and mounted to the only moving part, which only moves in one axis. The handle and the button are one part, connected to the moving part, clearly suggesting how to operate it, and what it will do. Its use is singular, and consequently obvious with a glance or a touch.

Figure 24: A chop saw is a simple tool, with limited function but obvious use..

3.5.7 Iteration

Blind woodworkers, like sighted woodworkers, often use constraints such as jigs and fences to make predictable cuts, routes, and holes. In fact, blind woodworkers seldom make freehand cuts. But those jigs and fences need to be set up first, and no matter how well we measure and prepare, sometimes things go wrong. As the adage goes, “I cut it twice and it’s still too short.” For those moments, iteration is a powerful principle in the workshop and for learning, because there can be no mistakes, only happy accidents.

Iteration is especially important because it is one way in which piloting is done and constraints are prepared. When a tool needs to be set up with a constraint, or piloted, those are iterative processes because they can rely on trial and error. Visually impaired woodworkers, who often prefer making constrained cuts over freehand ones, will therefore find iteration ac critical principle. It prepares instructors to teach students, and eventually students to teach themselves.

Iteration can also be used where some people may not rely on sight. This is the case on the lathe in the video below. As the student is cutting the wheel freehand, he simply stops here and there to asses his work by feel. Each time, he gets closer, until the job is done.

Iteration can also be used where people may not rely on sight, or when there is no way to create a constraint that produces a predictable outcome, or perhaps the outcomes is not yet defined. In this project students needed to turn a wheel on the lathe. No lathe copier was used, and instead students had to create a functioning wheel by feel, checking progress by feel, iterating closer to a goal. They would make cuts into the blank, feeling their work as they go to see if it fit the jelly beans that the wheel needed to capture (Figures 25 and 26). Another example of iteration is “sneaking up” on a measurement. For example, making tiny incremental changes to a thickness planer, or taking slivers off a piece until it fits, rather than measure and aim for a “known” dimension (7888, 00:43). See Appendix B for complete video footage.

Figure 25: A student using a lathe, iterating the shape as he cuts it by feel

Figure 26: A pile of wheel iterations.

3.5.8 Piloting

Blind woodworking instructors note that effective **piloting** can be especially important for visually impaired students who are novice. Piloting (along with iteration) is the means by which effective confirmations and constraints are devised. Therefore without piloting, many of the principles advocated for here and not deployable. But piloting is also something that should be taught to students, so that the can develop their own projects.

This study is intended to help sighted instructors prepare their workshops for visually impaired students. It is not uncommon that instructors ask about piloting under blindfold. Blindfolding and similar practices are are sometimes called “perspective simulations.” Many groups frown on perspective simulations, including blindfolds, because they are misleading and can promote discrimination. Sighted people are not good at being blindfolded, so they grossly underestimate what is possible for someone adept at non-visual problem solving techniques.

On the other hand some blind woodworking instructors will invite or even require sighted students to use a blindfold. In those cases, a visually impaired instructor is in control of the learning and perspective taking. They can control for a certain amount of misleading conclusions. If you do chose to pilot under blindfold, be sure that you situate your experience in an actual blind person’s experience and never just your own. Be certain never to assume any of your limitations are someone else’s. For a primer on piloting with blindness simulation, see “The Perils of Playing Blind: Problems with Blindness Simulation and a Better Way to Teach about Blindness,” by Silverman, 2015.

3.5.9 Progressive Disclosure

There is a lot of woodworking knowledge to be learned, a lot to disclose, and most of us cannot take it all in at once. Moreover educators not only need to foster knowledge inside an individual, they often need to diffuse that knowledge across a group. Progressive disclosure asks instructors to be thoughtful about how knowledge spreads from individuals to groups.

Groups of sighted learners might gather around a single tool and visually observe as the instructor operates it. They come away with a rough idea of how to use it. Visually impaired woodworking students often prefer a verbal description and hands-on lessons. The number of students that can perceive tactile tool training simultaneously is typically lower than sighted students. This means that rather than disclosing lessons to groups of students, it can be helpful to develop tactics that disclose lessons progressively, first into an individual student, and then through that student across a group.

When a single student has knowledge disclosed progressively, bit by bit, it means they have time to master a small, “micro-part” of woodworking. Each micro-part is woodworking is in effect a **chunk** of work. Once a student masters that chunk they can teach, or, "disclose," it to another student. In turn that student can exchange their micro-skill. This form of progressive disclosure not only reinforces learning, it means that multiple hands-on lessons can happen at once in the same shop, with less instructors. Instead of students gathered around one instructor, they are in groups, around each other.

In Figure 27 a student who gained enough confidence is showing another student how to use the router table. Figure 28 shows two student discussion their work, and sharing their knowledge. See Appendix B for complete video footage.

Figure 27: One student teaching another how to use the router table.

Figure 28: Two students are feeling and discussing their partially complete product.

3.5.10 Control

Control refers to the amount of control over learning that an instructor should give the student. Instructors should keep in mind that their lesson plans have a big impact on the level of control a student has over their learning path. Allowing a student control is empowering and builds confidence. But allowing them too much control, before the foundations of safety and shop etiquette are laid, can become problematic if they threaten to undermine confidence.

At first, for safety and for pedagogical concerns, the instructors set a learning path by choosing specific tools and tasks. Control over learning was progressively turned over to the students. After step 5 (see Chapter 3.5), students had many tools and tasks (work chunks) to choose from. On the last two days of class, instructors were at the students disposal to assist if requested, on whatever the students found interesting. Some students chose to learn how to use a digital talking protractor, which was not a required tool for the product (Figure 29). The instructor provided the digital protractor and then allowed them to explore it on their own. During class a student mentioned that he was interested in learning how to sharpen chisels, and the instructor delivered an impromptu tutorial on chisel sharpening (Figure 30).

Figure 29: Students exploring their own interests. The instructor is visible in the background.

Figure 30: Image showing an instructor giving a hands on demonstration of chisel sharpening at the student's request.

Blind woodworking instructors use the control principle in many different ways. Some blind instructors let students jump right into power tools, while others prefer to start with small hand tools. Hand tools allow students immediate freedom, but it can take longer to do things. Power tools have immediate results, but for movie students should be deployed in conjunction with constraints, like jigs and stops. Make efforts re to understand how the level of control will impact your students, this could be related to resources outside the shop, student goals, and student ability. Sometimes instructors will have all students make the same project, other times a student might be allowed to direct their own efforts. Each direction has its benefits, but whatever the level of control you choose to allow your students, be sure you can provide the required support. More freedom might actually entail more supervision, and higher student-teacher ratios, for example. Less freedom might be formulaic for a student, but can also allow them to work with less oversight.

Chapter 4: Member Check and Mainstream Review

After the observations were coded into categories suggestive of teaching principles (described in Chapter 3), the researchers sought to evaluate and refine those principles through a member check survey inclusive of blind woodworking instructors. Secondary review by design instructors from mainstream colleges and universities followed.

Member checks attempt to validate qualitative research findings by: a) asking participants to evaluate whether researchers have accurately rendered their experience, b) asking participants if the researchers understand the meaning of that experience to them, and c) whether the experience has been interpreted judiciously (Sandelowski, 2012). Cho and Trent describe the member check as process where data are played back to the participant to ensure researchers got it right (2006).

Review by instructors from mainstream colleges and universities was sought to identify how the teaching principles might interact with any practical and institutional considerations in that setting.

4.1 Member Check

In the member check, participant feedback was solicited from blind woodworkers and blind woodworking instructors. In addition to the small study sample from the Enchanted Hills camp, member recruitment was sought via email to known practitioners and from public online communities (such as Instructables and ww4b.org). Not all respondents had participated in the Enchanted Hills woodshop from Chapter 3, but they are considered “members” if they have significant experience as blind woodworkers. Based on the five survey responses, P2 and P5 had 10 or more years of teaching experience, while P1 had 6-10, and P4 had 4-6. Respondent P3 identified as a “practicing woodworker” since losing eyesight in 1984, although both formal and informal teaching experience is suggested in P3’s responses. All respondents were blind or visually impaired.

Participation was anonymous, with an option to be contacted for further comment. Of the five respondents, three of them (P2, P3, and P5) voluntarily identified themselves. Those three respondents also chose to participate in the survey verbally, reformatting the survey into a scripted interview. The remaining two respondents chose to remain anonymous and their means of recruitment is unknown. Complete survey responses are published in Appendix B.

4.1.1 Member Check Survey Format

The survey established the respondent’s years of experience (teaching or practicing) and status of visual impairment. Respondents were then presented with the teaching principles observed at Enchanted Hills and discussed in Chapter 3. A definition and an example photograph (with description) was provided for each teaching principle. Respondents were asked if they thought that the teaching principle was useful for teaching blind woodworking (*yes, no, or other*). Respondents were then invited to explain via long answer *why, or why not?* Lastly respondents were asked “if you already employ something like [teaching principle], can you provide a brief example.” (Figures

31 and 32). The final section of the survey asked general questions and invited spontaneous comments.

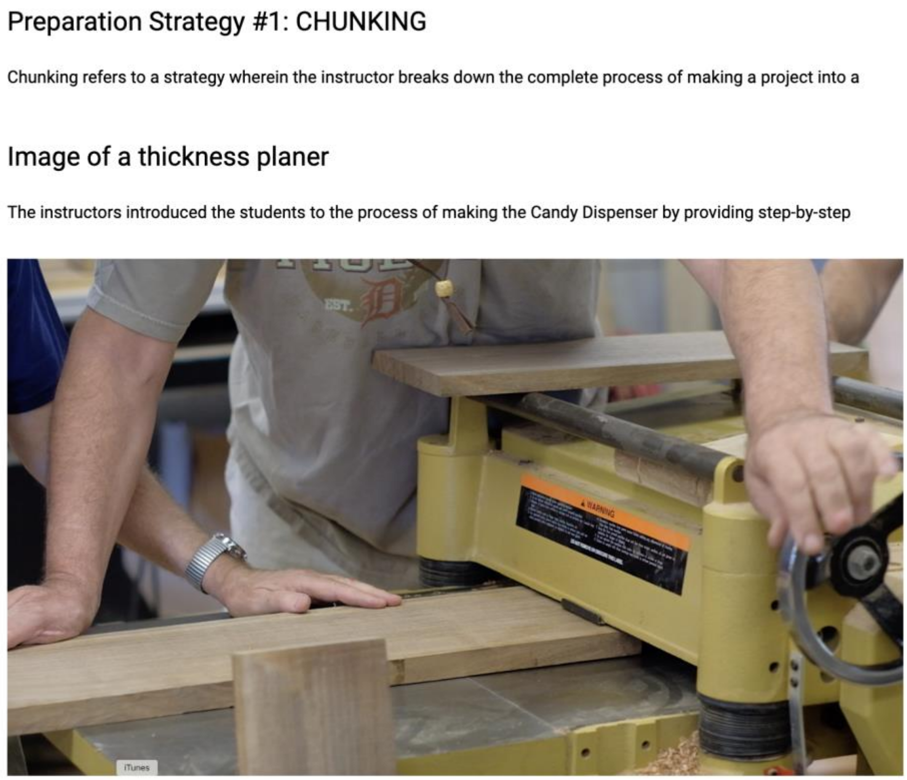
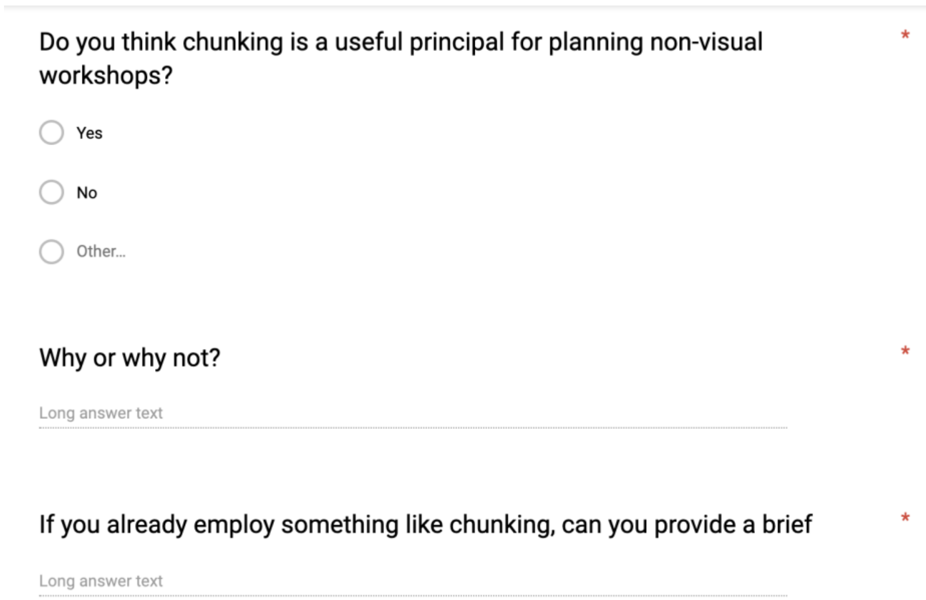


Figure 31: Screenshot of member survey.


Do you think chunking is a useful principal for planning non-visual workshops? *

Yes

No

Other...

Why or why not? *

Long answer text

If you already employ something like chunking, can you provide a brief *

Long answer text

Figure 32: Screenshot of member survey.

4.1.2 Member Check Survey Results

Question	yes	no	other
Do you think chunking is a useful principle for planning non-visual workshops?	5	0	0
Is constraint an effective way to make a tool accessible to a beginner?	4	0	1
Do you think piloting is a useful principle for planning non-visual workshops?	5	0	0
Do you think breaking down a project into a hierarchy make planning, describing and visualizing easier for students?	5	0	0
Do you think confirmation is a useful principle for planning non-visual workshops?	4	0	1
Does maximizing usability over flexibility help beginners learn tools?	3	0	2
Is modularity a helpful way to organize a workflow	4	0	1
Is progressive disclosure a helpful way to to teach, learn, and spread knowledge?	4	0	1
Can iteration or "guess and check" be used when constraint is not an option?	4	1	0
Is instructor control over the workshop necessary for beginners	5	0	0

Three of the teaching principles received a “yes” answer from all respondents (control, piloting, hierarchy). Feedback to the “*why or why not?”* questions on these principles were positive. One instructor provided their detailed heuristics on how one might decide what level of control to provide each student, starting from “white knuckling,” until the student starts to “relax, talk, use complete sentences” (P5). P4 remarked that they no longer pilot because they have “some proven projects,” and similarly P1 commented that but added “we have projects that we already know work. But we try to plan new ones by doing dry runs.” P3 who agreed that hierarchy was useful for visually impaired students, nevertheless cautioned that, “here is where you get into trouble with having everyone make the same project. For everyone to make the same thing, they need to know what they are making.” This was perhaps in reference to using hierarchy as a tool to describe a project to a group.

The survey question “Can iteration or ‘guess and check’ be used when constraint is not an option?” (Appendix C) was the only teaching principle that received a *“no”* answer (P3). No specific reasons as to why is given in the long answer feedback. P1 commented that iteration is useful, “especially when setting up jigs.” Jigs are one common form of constraint. In referencing constraint, P3 noted that “if you can’t make jigs then you need to learn how, which can be hard. also if you are making custom stuff this is no good.” It could be that respondent P1 means iteration is not an alternative to constraint, but that iteration is the principle by which one might configure a constraint. P3 is perhaps suggesting that this might be too difficult for a beginner, who has not yet “learned how.” P2 suggested they self-consciously employ iteration in their teaching elsewhere in the survey, albeit without using the exact term, as they “I individually modify, on the fly continually, each lesson for each student.”

The principle of confirmation received general acceptance. It received one *“other”* response and a few comments regarding safety and using guards. These response suggested that perhaps confirmation has two expressions: firstly that confirmations exist in the form of devices specifically designed to provide protection (writhing knife, sawstops, dust collector guard) (P3). Second is that some confirmations are user identified, or user generated, and non-generalizable (such as the planer table in figure 5 in Chapter 3). P3 and P4 note the importance of “getting comfortable with your tools,” but “never become overconfident,” respectively. P4 wrote that “another piece of wood can always be cut, but you can only cut your finger off once,” emphasizing the need to err on the side of caution, regardless of which teaching principles are in effect.

Validation of flexibility vs usability tradeoff was phrased as “Does maximizing usability over flexibility help beginners learn tools?” The researchers were trying to avoid confusion with expert practitioners. This question received three “*yes”* and two *”other”* responses; which were “sometimes,” (P1) and, “it can” (P4). One long answer noted there are cases “where a more complicated tool is necessary.” Of the 8 long answer responses, 6 are supportive of single use tools one emphatically noting that “those multi-tool things are boat anchors” (P5). One comment makes the very practical observation that using multi-tools results in boring set-up times where students have nothing to do, but that they can be good in small shops (P5). P4 suggested there are some benefits to teaching “harder tools,” but also that “changing up a tool” (likely referring blade, or bit) between steps is bad because you can never set a tool to make the same cut twice.

Modularity was approved with a “yes” response from all except one respondent, who chose “other.” That respondent explained that “it depends on where we want to get with this group. Where we want to take them” (P5). Reinforcement of the teaching principle was that it is “about getting people to work together,” and that while the “challenge is getting everyone's work to line up...it is also a measure of how much students are learning” (P4).

Progressive disclosure was similarly received, with four for *“yes”* and one *“other.”* The dissenting response was qualified with the conditional observation that “it all depends” (P5). Long answers were supportive, with one respondent suggesting that knowledge in this and similar fields (like auto body, upholstery) is cumulative and related (P3). The respondent noted that their building up knowledge from hand tools is important. This is unlike the workshop observed in Chapter 3, which began with power tools. It is unknown if this decision is related to age, safety, or skill level, but these considerations could confirm that, as P5 noted, “it all depends.”

4.1.3 Member’s Overall Impression:

The last section of the survey titled, “Final Review,” asked participants to score the following statements from 1-4, where 1 is “not at all” and 4 is “to a great extent:”

> *“Overall, do you think the strategies we outlined above could be useful to teach hands-on making activities to non-visual learners?”*
>
> and
>
> *“Overall, do you think these strategies might be useful for schools to include blind students in their woodworking classes?*

All respondents answered 3 (1 was “not at all” and 4 was “to a great extent”) to both questions. They were invited to explain their answers. One explanation was, “this is a good starting point. it is not the be all end all” (P2). Another clarified that “this could begin to help to create lessons, but it does not teach anyone how to use tools like marking and cutting” (P4). One respondent remarked that “if a teacher is going to try it, they need to believe that student will be able to do it” (P5).

The final field in the survey was the option to provide open-ended comments. One instructor mentioned that they often have to modify their lessons on the fly for every student. Another that this study might benefit from teaching including measuring techniques like the click rule. One unprompted mention of the importance of creating more courses for blind students, and not overteaching, or allowing students to explore. Several mentions of how woodworking builds confidence suggests that confidence is a desirable high level outcome,

> "I want to build the confidence to investigate these problems. and that confidence will come from using the big machines" (P2)
>
> "its about learning self confidence" (P3)
>
> "the first thing we gotta teach is confidence" (P3)
>
> "you aren't teaching them to be a woodworker. You are teaching them self confidence" (P3)
>
> "staggered [student ability levels in one classroom] speed it up a bit. confidence grows" (P5)

4.2 Mainstream Review

Informal interviews were conducted with instructors at colleges and universities in the Greater Toronto Area. These instructors were interviewed in an attempt to understand pedagogical, administrative, and human barriers that may impede the implementation of a blind woodworking course at a public institution.

Interviews were conducted at various points in the research, and include 4 instructors (referenced as W, X, Y, Z) who also maintain private practices in their fields. Interview notes are included in Appendix D. Two instruct in a woodshop, one of those as part of an industrial design degree (W), and the other as part of a fine art degree (X). Another interviewee is an instructor in an architecture program (Y), who has held high level administrative posts in a university setting and in private practice. The final instructor is an industry professional who, on retirement, became a sessional college instructor teaching electronic circuit design (Z).

4.2.1 Instructor Y

Y noted that certain institutionalized accreditation requirements, within schools, professional societies, and wider public policy, unintentionally create barriers to inclusion. For example, a certain number of jobsite hours are required to become a licensed, practicing architect. Job sites do not typically allow wheelchairs, for safety and other reasons. Consequently a student in a wheelchair would be unable to practice architecture, regardless of their performance in all other requirements. Interviewee Y noted they had observed scenarios similar to this one at various point in their career, in practice and education. Exclusions of these kinds are likely unintentional, and seem to occur at intersections of regulations, but this also makes them difficult to navigate. Y's observations in this regard are consistent with the cyclical model of exclusion introduced in Chapter 1.

4.2.2 Instructor Z

The instructor teaching electronic circuit design, interviewee Z, was an industry professional turned college instructor late in his career. This instructor is experiencing progressive visual impairment. The circuit design course is partially digital, that is, learning occurs on computers, but it still requires some manipulation of physical hardware. By using a mix of self-provided assistive devices (especially Dragon and JAWS), a visually impaired student was able to participate in “about 80-90% of the coursework,” according to the instructors reckoning. Both instructor Z and the school encouraged the student to remain in the program, and exempted the student from the few course requirement for which no alternative means of access was known. Midway through the program, however, the student terminated study by their own choice. Z speculates that the student withdrew from studies because of the students’ perception that the accumulations of exemptions would impact his performance in the intended field. Z expressed a desire to provide the student with more support, but that “nobody really had any solutions, and the school did not know how to help.”

4.2.3 Instructor X

Woodworking instructor X was interested in woodworking as an art practice, related to but distinct from design. In their words “I am an artist. For me, this is about coming to know who I am. It's a self-knowledge," but also that "the world can be better if I'm better," and "an artist needs full control to pursue whatever they do based on what they are drawn to." They remarked that an artist can't assume to know someone else's needs, which is perhaps what designers assume, or hope, to be able to do. X's thoughts on the capacity to "assume to know" someone else's needs is reminiscent if not consistent with theories on the importance of broadening the empathic diversity of designers discussed in Chapter 2.1.

Instructor X noted they had once been asked to adapt visual elements of their art practice into non-visual modes on short notice, and that experience was "a huge eye opener for me." Asked about adapting his workshop for blind students, "I would have to go through and education in ways of considering...if I had to I would enlist the help of blind students but I don't know if that would be helpful." The instructor did not mention enlisting the help of practicing blind woodworkers. The instructor also expressed concerns over safety, for example, power cords across the floor, which had obstructed a wheelchair user in a past cohort.

4.2.4 Instructor W

The second woodworking instructor, W, was more focused on practical questions regarding which tools blind woodworkers can use, and how they might use them. Perhaps this was indicative of the researcher not providing enough background, as any tool in common use in a sighted workshop (table saw, chop saw, router, sanders) is in common use in a blind woodshop (with the possible exception of a bandsaw). Answers to similar “how to” questions are documented in the blind woodworker manuals mentioned in Chapter 1.4. W also inquired about practical issues, such as how a blind student might find something (a tool, a project) that another student moved. This question is in a similar vein to interviewee X’s question about cable control. In the woodshop from Chapter 3, cables were typically routed overhead for stationary tools, and hand tools were plugged into outlets located on the tables. In general, students did not move other student’s tools and projects,

Interviewee W also related their experience with a student who had cognitive disability. The instructor predicted that the safety concerns with a blind student would “not be as bad” as compared to a student with cognitive disability.

Instructor W reacted positively to possibility of including blind students, and that their perspective would benefit everyone. W also held that “design skills are not innate,” and must therefore be learned to be leveraged, consistent with the need for inclusive design training discussed in Chapters 1 and 2. The program which W instructs in has an emphasis on job placement, and they find that students enter a variety of design professions, and that their “students learn to be problem solvers, even if they end up selling insurance.” This woodworking program is a full degree, and it is not possible to take woodworking courses related to this particular degree as electives. That arrangement is more related to oversubscription than a blanket policy. ↡

Chapter 5: Discussion

You aren't teaching them to be a woodworker, you are teaching them self-confidence. And that's the whole purpose of the shop.

- P3

5.1 Validity of suggesting "Teaching Principles"

The positive member check responses seem to suggest that, overall, the principles are an appropriate starting point, but with room for further research. Long answer comments indicate there is some discussion to be had regarding the interaction between principles, tools, tool operation, and goals.

For example, the students in the workshop observed during Chapter 3 were beginners operating expensive, industrial power tools. Respondents to the member check exhibited disagreement on preference to power tools over hand tools. P3 recommends that "hand tools are a great place to start," observing that when learning large, expensive, machines "how are you [a student] going to take this home with you?" Conversely P2 notes that "hand tools are good" but that "confidence will come from using the big machines."

Despite their difference in tool choice, both P2 and P3 agree on the importance of confidence. They want their students to feel like they can "fix a wobbly table leg" and have the "confidence to investigate those problems" (P2), and that "the first thing we gotta build is confidence (P3). Similarly, P5 notes that students are building both "skills and confidence" in tandem. P5 leverages that connection between skill and confidence to facilitate teaching. Students confidence is brought up because they can see the advanced skill of people who started where they did, and the steps in between,

> *by the time the 4th student comes in, the 1st one is pretty well self directed. The new student sees the first one and sees a success, and the levels in between, and believes in it. It's a slow period at first for new students, but staggered [student ability] will speed it up a bit. confidence grows.*

Thus in P5s pedagogy, once confidence is taught to one student, it trickles down and encourages confidence in new students, whose skills grow until they become the "old" students, creating a positive feedback loop. Once confident, students' will learn whatever is available to them. Note also that P2 equates confidence with the ability "to investigate problems." We might infer that confidence is the real goal, because confidence facilitates learning and interventions that make students' live better. The tools used to build that confidence (hand, power, or other) are flexible. This is supported by Vissier's generic design hypothesis (that all tools of design have similar underpinnings).

The member-identified need to instil confidence is what suggested this study should identify high level teaching principles, rather than document a tool-by-tool "how too." Prescriptive recommendations for things like tool operation and taking measurements is already available in manuals written by blind woodworkers such as those at ww4b.org (by Larry Martin) or visionaware.org (by Gil Johnston). No source is available for what P2 identified as the flexibility to “individually modify, on the fly continually, each lesson for each student.”

Imagine the common scenario where a student must rip a straight cut down a length of wood, perhaps 4 feet long. This might be performed on a panel saw (large, expensive power tool), a table saw (large, middle cost power tool), a circular saw (small, inexpensive power tool), or a hand saw (inexpensive hand tool). In all cases, no matter the tool, some kind of constraint (likely a fence or clamps) is deployed to ensure the cut runs straight and safe. Therefore the flexible knowledge that a student can “take home” is the constraint principle, which they can apply to whatever tool is available.

5.2 Teacher Training and Safety

“it’s not about blindness. It doesn't matter if you are or aren't sighted, if you put your finger into the saw you will lose your finger.”

- P3

While teaching principles are flexible, they are perhaps too open ended as an entry point. Instructors interviewed from outside the blind community expressed that they would “need an education” (X), and need “the tools” (Z) to teach blind students, in addition to questions about tool operation. Specific practical concerns were also mentioned, often around safety. Blind woodworkers have solved most if not all of those concerns, but those solutions must be provided to mainstream instructors so they have confidence in the students.

Instructor W asked how blind students would navigate general shop hazards, like carts, moving projects, and open pathways. Visually impaired woodworkers, and visually impaired people in general, already have refined methods moving around safely. Sometimes students used their cane when walking across the woodshop, but not always. During the study recorded in Chapter 3, no injuries were observed. The instructor who delivered that workshop told the researcher that "when I someone hurts themselves around here, they are most often than not sighted" (Appendix E). Blind woodworker P4 suggests, as a general approach, to "emphasize that another piece of wood can always be cut, but you can only cut your finger off once." In effect, no safety precautions peculiar to the visually impaired community were observed in the study, except the non-visual confirmations mentioned in Chapter 3, if they can be considered as such.

Instructor X specifically mentioned they were concerned about power cord management. Extension cords and power cables can be a tripping hazard, and one that can pull a tool from someone's hands. In the blind wood shop described in Chapter 3, extension cords were observed on the floor but only rarely, and no tripping was observed. Electrical power for stationery tools was usually routed through the ceiling and down to the tools. Workbenches had outlets for powered hand tools. Such an arrangement that removes cables from the ground would be beneficial to all users, including wheelchair users, which instructor X has previously enrolled in their classroom.

College woodworking instructors W and X both rely on sound to increase safety. A quiet shop is necessary to identify the sounds related to improper tool use, or student injury. Instructor X mentioned that a wall erected in their woodshop made it difficult to hear what was happening and anticipate problems. Instructor W does not allow earbuds or phones in their shop, and that shouting is only in case of emergency. There may be a slight conflict with the practices of blind woodworking in this case. In Chapter 3 when something was moved or misplaced in the blind workshop, a student might ask their peers if anyone has seen it. If those requests are too loud, they could conflict with the low voice rules of sighted workshops. Otherwise, the utilization of sound for safety and for tool operation is similar if not identical for both groups. If anything, using sound to identify injuries and improper tool use is more vital in the blind woodshop.

Instructors from the general population wondered about how tools are stored and located in a blind classroom. Some blind woodworking instructors use tactile and braille labelling, but the workshop studied in Chapter 3 did not. P4 indicates that “if a student is unfamiliar with a shop, an orientation has to happen.” The instructors in Chapter 3 described the shop verbally on the first day. As one stationary instructor described the location of tools in the shop, another was moving to corresponding spots, and tapping on the tool being located. In other instances, perhaps with smaller groups, orientation is left to the student to do at their own pace. P3 recalls their first experience in a woodshop, “my first project was a cereal cabinet and my shop instructor made me go get the wood out of the storage closet full of wood that I had never been in, up on a ladder, and it was hard.”

According to P4, the teacher and the student are actually co-orienting, “I learn them, but they learn as well, touching all these things, sandpaper, feeling the grit, 100, 400, 800, showing them channel locks. no braille. no tactile mapping. no planning (at first).” P4 understands the need to expose the general population to the abilities of blind woodworkers, “I think if a teacher is going to try it they need to believe the student will be able to do it.”

5.3 Evidence of Learning

Students participating in the workshop described in Chapter 3 demonstrated signs of learning and life enrichment. The model used to locate indicators of learning is that developed by Petrich, Wilkinson, and Bevan (2013). Their indicators of learning were developed for maker-style classroom, and support the vision of science learning advocated by the National Research Council (Petrich et al., 52). Petrich et. al.’s illustration of learning “comes about through a process of design thinking and principles,” which is complementary to the design principles that underpin the teaching principles identified in Chapter 3 (p. 65). The model proposes four categories that indicate learning, Engagement, Intentionality, Innovation, and Solidarity. Petrich et all provide example behaviours within those categories, like expressions of joy, evidence of self direction, complexification, and sharing tools and strategies.

5.3.1 Engagement

Students were recorded making deductive leaps of logic, a sign of Engagement. For example in a viedo recording when being taught how to sharpen chisels, a student takes a guess and clarifies an uncertain lesson given by an instructor, “so that is to say, this plate here?” Another student was observed making a deductive leap and exclaiming, “...and that *must* exist,” while another student exclaims in a eureka moment “ok. Yes….ohh, yea, yea yea!” Some students were returning for the 2nd and 3rd time, and some were staying for the “advanced” course offered the following week.

5.3.2 Intentionality

Expressions of intentionality also existed, in the form of self-direction. One student brought his own tools to the classroom, which were not part of the prescribed project, hoping to explore them in a shop more fully equipped than his own, and with peers. Other students pursued their own projects in their spare time, like building a box. Two students asked to learn chisel sharpening, which was also not part of the lesson plan.

5.3.3 Innovation

There was less evidence of innovation to the candy dispenser built in Chapter 3. One student did alter the router bevel along the body of their candy dispenser (Figure 33). The student explained that it was not meant to be a handle, but to “suggest” a handle by feel, and by extension how a visually impaired user might hold and operate the product

(Appendix E). In one video clip, two blind woodworkers are seen discussing how they would modify their canes to better suits their preferences.

Figure 33: The right angle bevel on the side of this product was a student's innovation

5.3.4 Solidarity

Solidarity was built into the workshop by the instructors through progressive disclosure. As the students progressed in ability, instructors were increasingly hand off, and students were encouraged to seek help from one another. Three students were seen working together to figure out how a talking level pairs with an iphone over Bluetooth in a video recording, while the instructor remains silent. Students and instructors expressed their sense of community vis-a-vis the sighted, video camera wielding researcher with jokes like “what's the matter, don't you like the colour of my shirt?”

(Appendix E), and “we are almost done with the makeup.” “Woodworker” quips occurred as well. One student joked in self-deprecation, “I cut it twice and it’s still too short,” while another playfully teased a peer when noticing a mistake in a project “who did that!? *Jerry?*”

It should also be noted students in the Chapter 3 study all recognized each other from community groups, such as the Blind Abilities Podcast, ww4b.org, and even a Subaru Commercial. Jeff Thompson, an instructor in the workshop, is host of Blind Abilities and has published at least two podcasts interviewing students since this writing.

5.4 Confidence, related to Education and Employment

Students with healthy levels of confidence have been shown to engage in learning activities more readily, put more effort into those activities, and be more persistent in their attempts (Schunk and Miller, 2002). Self-confidence has been noted as a characteristic of "creative” people (Martindale, 1989, Davis, 1986), such as one might expect to find in design fields. A study of science students in Taiwan showed that students with higher confidence had higher achievement than those with lower confidence (Chang and Cheng, 2008). Under-confident students with (unspecified) disabilities “perceive their educational opportunities to be limited,” even where they do not lack ability (Melnikova, 2018, p. 4).

The woodworking instructors who participated in the member check, and instructors from the public university, all agree that woodworking builds confidence. Multiple woodworking instructors observe that woodworking builds confidence in Chapter 4.1.3. Instructor W specifically mentioned that woodworking builds confidence (Appendix D), and Instructor X alluded to it in 4.2.3 when referencing the self-conscious value of individual growth. Clay Gurganus, a professional woodworker with complete vision loss, notes that when he teaches his trade to other blind students, they ask themselves “if I can do this, what else can I do with my life?” (Mika, 2016).

5.4.1 Confidence and the Proposed Teaching principles

Shumow and Schmidt (2014) propose four concepts in confidence, which can be used to identify the growth of confidence in the woodworking study conducted in Chapter 3. According to them, confidence is promoted or undermined by Prior Success, Observing Others (role models), Persuasion (encouragement, feedback, achievable but aspirational expectations), and Emotional Experience. These four concepts will be used to identify confidence building in the research data.

Prior Success

Prior success means that individual students will refer to their previous achievements when gauging the size of the next learning challenge they will attempt to tackle. Teaching principles like control, piloting, confirmation, and constraint are especially calibrated to ensure prior successes and confidence. These principles involve preparing the workshop, or any classroom, for students to succeed. As P1 remarked, instructors must not exert “too much control. just enough to make sure students learn.” Thus by controlling or calibrating the challenge so that individual students feel the rewards of learning, but not enough to risk catastrophic failure, the woodworking instructors ensured that today's lessons were tomorrow's "prior success."

Observing Others

By observing others, students can be inspired, have their preconceptions about the abilities reshaped by people like them, or observe a learning journey and transpose themselves onto it. The instructor from Chapter 3, George Wurtzel, and member check respondent P3, for example, are role models in the blind woodworking community. Jeff Thompson, another instructor from Chapter 3, was recognized by his voice as the host of the Blind Abilities Podcast by students (Appendix F). On recognizing Jeff, one student expressed his excitement, comfort, and "I'm home, I'm with the folks that I'm here to work with." (Thompson, 2018).

Progressive disclosure, which was explicitly practiced in the "growing" of knowledge laterally through students in Chapter 3, and horizontally in P5's classroom by his own instructional design (Chapter 4.1.2), is in practice the creation of many mini-roll models. Student can see each other starting for the same space, and mutually growing, and sharing that growth. In the workshop studied in Chapter 3 such progressive disclosure was made possible by chunking tasks, and modular parts conveyed in a hierarchy that allowed one student could learn and teach another, and students could work together.

Persuasion

Various forms of persuasion are suggested by Shumow and Schmidt, but in general they refer to encouragement, and convincing that aspirational expectations within reach - while actually keeping them in reach. Application of the flexibility-usability tradeoff as observed in Chapter 3 is a form of persuasion. Approachable tools are presumably more encouraging, because they are less intimidating, and it is easier to keep them within reach. By contrast, highly flexible tools that are less usable are more difficult for a novice to learn, and perhaps harder to persuade one to attempt them. The teaching principle of hierarchy is another example of persuasion. Effective hierarchy can break a complex project down into simpler, more manageable parts, so that a student can be persuaded to approach them in chunks rather than a daunting single task.

Emotional Experience

Experience in a classroom must be emotionally positive to build confidence. Positive emotions were suggested by the camaraderie of the students in Chapter 3. They worked together on project, joked together, recognized each other as community members, lived together for a week, and some were returning for the second and third time. Negative emotional experiences, like failure, are mitigated by the emphasis of iteration as a teaching principle. Iteration, otherwise known as “trial and error,” positions error as an entirely normal step in the creative process, rather than something negative. Iteration downplays the impact of error as an negative emotional experience, students were casually encouraged to “try another one” (7575).

5.1.2 Gender and Confidence

The correlation between confidence and success in STEM fields is significant, and in particular adolescent girls seem to require higher baseline levels of confidence to engage in STEM activities (Shumow and Schmidt, 2014). Woodworking may be an especially effective confidence building STEAM activity for girls. According to member check respondent P5, “girls come in [to the woodshop] eager as heck. this isn't what they are normally presented with, nothing pink, nothing clean or easy” (Appendix C). While male students overestimate their knowledge, “they don’t actually know anything.” Female students are “free to be learners,” and may perceive a greater growth in knowledge. If P5s observations are generalizable to other woodshops, then woodworking may be effective in reducing gender gaps in STEM, and not only for visually impaired students.

5.5 Considerations to Support Independent Problem Solvers

STEAM education, and its relationship with design, suggests that it might empower people to solve problems in ways relevant to them. That is to say, if STEAM such as woodworking enables design, and design is how useful things are made, then we can predict that STEAM education will result in the creation of useful products by and for its students. This is perhaps happening in the wider context of Do-It-Yourself creation of Assistive Technologies (DIY-AT). DIY-AT may further suggest that that STEAM is a potential pathway to design practice.

At the very least, a demand for access to centers for DIY-AT exists. Hurst and Tobias predict that DIY assistive technology will emerge wherever there is access to makerspaces (2011). The University of Washington College of Engineering surveyed its students and found that disabled students wanted maker-type labs to create their own solutions for their own needs (2015). Among the students at the woodworking course in Chapter 3, two students were observed discussing how to modify their canes with custom tips that fit their needs and preferences.

There was evidence of a blind DIY-AT community is nascent in the context of blind woodworking. Student participants in the Chapter 3 study were heard discussing to another how to make personalized modifications to his cane (Figure 34). Specifically, they were interested in the size and shape of the tip, the behaviour of certain materials, and the tradeoffs of using one material over another. It is a small example of a STEAM classroom creating empathic design outputs, but also a very real one.

Figure 34: Two students discussing their DIY-AT design changes to a cane tip

Two of the students were later interviewed by the Blind Abilities podcast about their time at the woodworking camp. One remembered his experience when hearing the familiar sound of two of the instructors' voice, George Wurtzel and Jeff Thompson. "I knew the voices and I said, 'I'm home, I'm with the folks that I'm here to work with' " (Thompson, 2018, Oct. 1). Another student, employed as a computer analyst, shared his story of creating a woodshop the kitchen of his Montreal apartment where he now makes guitars part time (Thompson, 2018, Oct. 15). These are taken as evidence of a growing community of DIY, if not specifically DIY-AT.

5.6 Summary of Findings

The member check supports that the teaching principles are a promising beginning to the inclusion of visually impaired students in woodworking classrooms, STEAM classrooms, and by extension, design education. Interviews with instructors from the general population suggest they are receptive to welcoming a broader student audience, but with come concerns. Many of their concerns are practical in nature, and already solved by visually impaired woodworkers in ways published in publicly available documents. This finding rewards the approach of suggesting high level teaching principles, but it also highlights the necessity for instructor training in blind specific tool use.

Based on the indicators of learning from Petrich et al., it was found that the students in the woodworking course engaged in meaningful learning activities. Instructors also widely agreed on the importance of confidence, how it is developed by woodworking, and Shumow and Schmidt show that confidence is key to STEM learning. Using their indicators, it was shown that both woodworking and the teaching principles from Chapter 3 can directly support confidence building.

There is also a DIY and community component to woodworking. That DIY know-how is positioned within literature that suggests such maker-style abilities translate to the power for users to design their own solutions. It might be inferred by extension that woodworking increases the potential for educational outcomes, and perhaps enables the design and production knowledge similar to, or useful in, professional practice.

6 Conclusion and Future Work

Preliminary research noted that disabled students tend to enroll in post-secondary education half as much as the general population, drop out more often, and that disabled graduates find employment half as often as the general population. This study was conducted to approach that problem by identifying inclusive for-us-by-us instruction methods developed by visually impaired woodworkers, and how those can be used by mainstream instructors to create educational pathways to professional design practice. The researchers were also interested in what practical obstacles to inclusive woodworking education would be anticipated by mainstream instructors.

Based on the general transferability of STEAM education to design practice as discussed in chapters 1.2 and 2.2, and the evidence of learning in 5.3, woodworking seems to be a viable educational pathway towards inclusion in design professions for visually impaired students. The suggested teaching principles also directly facilitated the development of confidence, a key component of for STEM education (5.4). Further, woodworking seems to be usefully situated within the DIY-AT community (5.5), and showed a nascent evidence of a empathic design community.

This study reports lessons learned from observing one community of blind woodworkers and collected feedback from a few experts external to that community. However, this study has by no means exhausted all opportunities to engage visually impaired woodworkers or workshops. Many centres for blind training offer woodworking or industrial arts training, such as the CNIB and Utah State Division of Services for the

Blind and Visually Impaired. Future investigation should involve members from those institutions, and more unaffiliated blind woodworkers and practitioners.

The teaching principles also need to be tested out of group, that is, by sighted instructors. A pilot woodworking course designed by sighted instructors could be tested by volunteers. This is the most needed next step. Once instructors from public colleges attempt to deliver a course, they can take their pain points to a wider audience of blind woodworkers for assistance.

Lastly this study could become a locus not only for research into for-us-by-us education that facilitates beneficial maker and DIY opportunities for disabled populations, but how to leverage that to make public education more inclusive. ↡

References:

Applied Arts. (2019) Homepage. Retrieved from https://appliedarts.ca/. Retrieved on April 6, 2019.

Agkathidis, A. (2016). *Generative Design: Form-finding Techniques in Architecture.* London: Laurence King Publishing.

Amalraj, A., Sahayaraj, W., Jothi, S., Dharmalingam, V., Rajendran, S. (2016). Teaching of Group Theory to the Blind Student Through Violin. *International Journal of Nano Corrosion Science and Engineering,* 3(4). 104-11.

Anderson, Eric. Designing Blind: An approach towards universal design. Carnegie Mellon. http://www.idsa.org/sites/default/files/Designing%20Blind.pdf. Retrieved on: March 20, 2018.

Alper, Meryl (2012). Making Space in the Makerspace: Building a Mixed-Ability Maker Culture. *IDC'13,* June 24–27

Barnidge, T. (March. 15, 2013) Barnidge: Blindness is no handicap for this woodworker. *East Bay Times.* Retrieved from: https://www.eastbaytimes.com/2013/03/15/barnidge-blindness-is-no-handicap-for-this-woodworker/

Basham, J. D., Israel, M., & Maynard, K. (2010). An Ecological model of STEM education: Operationalizing STEM for all. *Journal of Special Education Technology,* 25(3), 9.

Basham, J. D., & Marino, M. T. (2013). Understanding STEM education and supporting students through universal design for learning. *Teaching Exceptional Children,* 45(4), 8-15

Belcastro, F. P. (1993). Teaching addition and subtraction of whole numbers to blind students: A comparison of two methods. *Focus on Learning Problems in Mathematics,* 15(1), 14–22.

Bequette, J., & Bequette, M. (2012). A place for ART and DESIGN education in the STEM conversation. *Art Education,* 65(2), 40-47.

Bizier, C., Till, M., Nicholls, G. (2014). Learning disabilities among Canadians aged 15 years and older, 2012. Canadian Survey on Disability, Statics Canada, Minister of Industry.

Bizier, C., Ricardo, C., Walpole, A. (2012). Seeing disabilities among Canadians aged 15 years and older, 2012. Canadian Survey on Disability, Statics Canada, Minister of Industry.

Bødker, S (1996). Creating conditions for participation: Conflicts and resources in systems design. *Human Computer Interaction.* 11 (3): 215–236.

Burgstahler, S. (2013). *Universal design in higher education: Promising practices.* Seattle: DO-IT, University of Washington. Retrieved from www.uw.edu/doit/UDHE-promising- practices/preface.html

Buchanan, R. (2001). Design and the New Rhetoric: Productive Arts in the Philosophy of Culture. *Philosophy & Rhetoric,* 34(3), pp. 183-206.

Caregiver Products. (2019). Ankle AFO Assist Dressing Aid. Retrieved from https://www.caregiverproducts.com/ankle-afo-assist-dressing-aid.html.

Calder, M., Cohen, R., Lanzoni, J., Landry, N., & Skaff, J. (2007). Teaching data structures to students who are blind. Proceedings of the 12th annual SIGCSE conference on Innovation and technology in computer science education. 87-90

Cassim, J. (2010). Designing effective user interactions – examples from the challenge workshops. Proceedings of the 3rd International Association of Universal Design. In: McGinley, C., and Dong, H. (2011). Designing with Information and Empathy: Delivering Human Information to Designers*. The Design Journal,* 14:2, 187-206.

Coleman, D. (2006, August 7). More than Meets the Eye. *The New York Times.* Retrieved from: https://www.nytimes.com/2006/08/27/fashion/27POSS.html

Chet, R. (2004). *Certain to Win: the Strategy of John Boyd, Applied to Business.* Xlibris: USA.

Chun-Yen Chang & Wei-Ying Cheng (2008) Science Achievement and Students' Self-confidence and Interest in Science: A Taiwanese representative sample study. *International Journal of Science Education,* 30:9, 1183-1200.

Cho, J., & Trent, A. (2006). Validity in qualitative research revisited. *Qualitative Research,* 6(3), 319–340.

CNIB. (2019). Woodturning. Retrieved from https://cnib.ca/en/event/woodturning?region=on

Daugherty, M. K. (2013). The Prospect of an "A" in STEM Education. *Journal of STEM Education: Innovations and Research,* 14(2), 10.

Davis, G. A. (1986). *Creativity is forever (2nd ed.).* Dubuque: Kendall Hunt Publishing Company

Dawe, M. 2006. Desperately seeking simplicity: how young adults with cognitive disabilities and their families adopt assistive technologies. In Proceedings of the SIGCHI conference on Human Factors in computing systems (CHI '06), ACM. 1143--1152.

Dunn, C., Rabren, K. S., Taylor, S. L., & Dotson, C. K. (2012). Assisting Students With High-Incidence Disabilities to Pursue Careers in Science, Technology, Engineering, and Mathematics. *Intervention in School and Clinic*, 48(1), 47–54.

Dym, C., Agogino, A., Ozgur, E., Frey, D., Leifer, L. (2005). Engineering Design Thinking, Teaching, and Learning. *Journal of Engineering Education,* 94(1) 103-120.

Giles, Emilie; van der Linden, Janet and Petre, Marian (2018). Weaving Lighthouses and Stitching Stories: Blind and Visually Impaired People Designing E-textiles. In: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems.

Glaser, B., Strauss, A. (2006). *The Discovery of Grounded Theory: Strategies for Qualitative Research.* New Jersey: Aldine Transaction

Goel, V. Pirolli, P. (1988). *Motivating the notion of Generic Design Within Information Processing Theory: The Design Problem Space.* University of California at Berkeley. Retrieved from: https://apps.dtic.mil/dtic/tr/fulltext/u2/a210266.pdf

Hadley Institute for the Blind and Visually Impaired. (2019). Sawdust 101 - Adaptive Techniques For Blind Woodworkers. Retrieved from https://hadley.edu/SeminarDetails.asp?sid=23

Henriksen, Danah (2017). Creating STEAM with Design Thinking: Beyond STEM and Arts Integration. *The STEAM Journal,* 3(1) Retrieved from http://scholarship.claremont.edu/steam/vol3/iss1/11

Hitti, M. (2004). Designing His Vision. *Profiles: Journal Of National Kitchen And Bath Association*. 3(3).

Holt, M. (2011). The Limits of Empathy: Utopianism, Absorption and Theatricality in Design. *The Design Journal,* 14:2, 151-164.

Holmes, K. (2018). *Mismatch: How Inclusion Shapes Design.* Cambridge: MIT Press.

Hong, L., Page, S. (2004). Groups of diverse problem solvers can outperform groups of high-ability problem solvers. *PNAS.* November 16, 2004 101 (46) 16385-16389

Hwang, J., Taylor, J. (2016). Stemming on STEM: A STEM Education Framework for Students with Disabilities. *Journal of Science Education for Students with Disabilities,* 19(1).

Iowa Department for the Blind. Orientation Centre Classes. Retrieved from https://blind.iowa.gov/living/orientation/classes

Iowa Commission for the Blind. (date not given). What Is The Iowa Commission For the Blind? Des Moins: Iowa. In Jernigan, K. (1970). *Blindness: The Myth and the Image.* [Public Address]. Retrieved from https://nfb.org/Images/nfb/Publications/convent/banque70.htm

Jernigan, K. (1970). Blindness: The Myth and the Image. [Public Address]. Retrieved from https://nfb.org/Images/nfb/Publications/convent/banque70.htm

Kelley, D. and Kelley, T. (2015). *Creative Confidence: Unleashing the creative potential within us all.* Harper Collins, USA.

Kuznetsov, S., Fernando, P,. Ritter, E., Barrett, C., Weiler, J., Rohr, M. (2018). Screenprinting and TEI:Supporting Engagement with STEAM through DIY Fabrication of Smart Materials. *TEI 2018,* March 18–21, 2018, Stockholm, Sweden. Pages 211-220

Lidwell, W., Holden, L., & Butler J. (2011). *Universal Principles of Design, 125 Ways to Enhance Usability, Influence Perception, Increase Appeal, Make Better Design Decisions, and Teach through Design.* Beverly, Massachusetts: Rockport Publishers, Inc.

Ludlow, B. (2013). Growing STEM as a pathway to the future. *Teaching Exceptional Children,* 45(4), 4.

Martindale, C (1989). *Handbook of creativity: Personality, situation, and creativity.* USA: Springer

Martin and Hanington (2012). *Universal Methods of Design: 100 Ways to Research Complex Problems, Develop Innovative Ideas, and Design Effective Solutions.* Massachusetts: Rockport.

McGinley, C., and Dong, H. (2011). Designing with Information and Empathy: Delivering Human Information to Designers. *The Design Journal,* 14:2, 187-206.

Menichinelli, M. (n.d.). Open P2P Design [online]. Available at: http://www.openp2pdesign.org/about/ [accessed 7 December 2010].

Metatla, O., Bryan-Kinns, N., Stockman, T., Martin, F. (2015). Designing with and for people living with visual impairments: audio-tactile mock-ups, audio diaries and participatory prototyping. *CoDesign*, 11(1), 35–48. Retrieved from: https://doi-org.ocadu.idm.oclc.org/10.1080/15710882.2015.1007877

Meissner, J., Vines, J., McLaughlin, J., Nappey, T., Maksimova, J., Wright, P. (2017). Do-It-Yourself Empowerment as Experienced by Novice Makers with Disabilities. *DIS 2017*, June 10-14

Melnikova, E. (2018). Self-Confidence of Students with Disabilities in College Level Linguistic Class. *SHS Web of Conferences,* 50(01103). Retrieved from: https://doi.org/10.1051/shsconf/20185001103

Mote, C., Strelecki, K., and Johnson, K. (2014). Mote, C., Strelecki, K., & Johnson, K. (2014). Cultivating high-level organizational engagement to promote novel learning experiences in STEAM. *The STEAM Journal,* 1(2).

Mika, Dan. (2016, September 24). Ames man's woodworking knack is all in the touch. Ames Tribune. Retrieved Feb 11, 2018 from, http://www.amestrib.com/news/20160924/ames-mans-woodworking-knack-is-all-in-touch

National Federation for the Blind. (2019). Blindness Statistics. Retrieved from: https://nfb.org/resources/blindness-statistics

Norman, D. (2013). *The Design of Everyday Things.* New York: Basic Books.

Olson, T. (2017, March 8). So, what is design anyway? Retrieved from: https://medium.com/the-design-innovator/https-medium-com-the-design-innovator-so-what-is-design-anyway-4f99128b51c4

Petrich, M., Wilkinson, K., Bevan, B. (2013). Chapter 5: It Looks Like Fun but are They Learning? In Margaret, H., and Kanter, D. *Design, Make, Play: Growing the Next Generation of STEM Innovators*. New York: Routledge.

Piro, J. (2010). Going from STEM to STEAM: The Arts Have a Role in America's Future, Too. *Education Week,* 29(24), 28–29.

Platz, J. (2007). How do you turn STEAM into STEAM? Add the arts. *Ohio Alliance for Arts Education,* 1-5.

Ralph, P. and Wand, Y. (2009). "A proposal for a formal definition of the design concept". In Lyytinen, K., Loucopoulos, P., Mylopoulos, J., and Robinson, W., editors, Design Requirements Workshop, p. 109. Springer-Verlag doi:10.1007/978-3-540-92966-6_6.

Rowe, P. (1991). *Design Thinking.* London: MIT Press

Sanelowski. (2012). *The Sage Encyclopedia of Qualitative Research Methods.* L. M. Given (Ed.). Thousand Oaks: SAGE Publications, Inc.

Sanoff, H. (2000). *Community Participation Methods in Design and Planning.* New York: John Wiley & Sons

Salvo, L. (2003). US Patent No. US 6,575,754B2. Retrieved from: https://patents.google.com/patent/US6575754

Scherer, M. J. (1996). Outcomes of assistive technology use on quality of life. *Disability & Rehabilitation. Informa Healthcare.* 18(9): 439--448.

Schunk, D. H., and Miller, S. D. (2002) *Self-efficacy and Adolescents' Motivation.* In F. Pajares and T. Urdan (Eds.) *Academic Motivation of Adolescents.* Connecticut: Information Age Publishing.

Scrivener, S., Ball, L. and Woodcock, A. (eds). (2000). *Collaborative Design: Proceedings of Codesigning 2000.* London: Springer

Sheridan, K M., Rosenfeld Halverson, E., Litts, B. K., Brahms, L., Jacobs-Priebe, L., Owens, T. (2014). Learning in the Making: A Comparative Case Study of Three Maker Spaces. *Harvard Educational Review,* 84(4). 505-565

Shumow, L., and Schmidt, J. (2014). *Enhancing Adolescents' Motivation for Science: Research-Based Strategies for Teaching Male and Female Students.* Thousand Oaks, CA, US: Corwin Press.

Shop Class (1934). *Junior-Senior High School Clearing House.* 9(3) p. 154.

Simon, H. A., (1981). *The Sciences of the Artificial* (Second Edition). Cambridge: MIT Press.

Simon, H. A. (1996). *The Sciences of the Artificial* (3rd, rev. ed. 1996). Cambridge, MA: MIT Press.

Silverman, A. (2015). The Perils of Playing Blind: Problems with Blindness Simulation and a Better Way to Teach about Blindness. *Journal of Blindness Innovation and Research,* 5(2). Retrieved from: https://www.nfb.org/images/nfb/publications/jbir/jbir15/jbir050201.html

Silverman, A. Gwinn, J., Van Boven, L. (2014). Stumbling in Their Shoes: Disability Simulations Reduce Judged Capabilities of Disabled People. *Social Psychological and Personality Science,* 6(4), 464–471.

Sparkfun. (2014). Enginursday: DIY Assistive Technology Mouse. (Taylor, C.). Retrieved from: https://www.sparkfun.com/news/1570?utm_source=&utm_campaign=&utm_medium=&utm_term=

Stack Overflow (2017). Developer Survey Results 2017. Retrieved from: https://insights.stackoverflow.com/survey/2017

Strauss, A. L., & Corbin, J. (1998). *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory 2nd ed*. Thousand Oaks: Sage.

Taylor, M. (2005). Access and Support in the Development of a Visual Language: arts education and disabled students. *The International Journal of Art and Design Education,* 24(3), 325-333.

Thomas, J. C., Carroll, J. M. (1979/1984). The psychological study of design. *Design Studies,* 1(1), 5-11. Also in Cross, N. (Ed.). (1984). *Developments in Design Methodology,* 221-235. Chichester, England: Wiley.

Thompson, J. (2018, Oct 1). Meet Bob Geyer at Woodworking for the Blind, WW4B, and the Enchanted Hills Camp in Napa, California. Blind Abilities. Podcast retrieved from https://blindabilities.com/?p=3995

Thompson, J. (2018, Oct 15). Meet Trevor Astrope: Computer Analyst, Woodworker and Guitar Builder, at WW4B and the Enchanted Hills Camp. Blind Abilities. Podcast retrieved from https://blindabilities.com/?p=4023

Tillotson, K. (July 24, 2014) My eyes are down here: Blind craftsman George Wurtzel's magic touch. *The Sun.* Retrieved from: http://www.iowastatedaily.com/news/university-employee-finds-light-in-the-darkness/article_53c3a8a1-3be0-5a78-bf68-47f2c433b4cb.html

Hughes, B. (2010). Park Forest Middle School STEM Education Fair 2010. *Technology and Engineering Teacher,* 70(2), 32-35.

Hurst, A., Tobias, J. 2011. Empowering individuals with do-it-yourself assistive technology. In *ASSETS '11: Proceedings of the 13th International ACM SIGACCESS Conference on Computers and Accessibility,* 11-18, New York, NY, USA: ACM.

Hwang, J., Taylor, J. Stemming on STEM: A STEM Education Framework for Students with Disabilities. *Journal of Science Education for Students With Disabilities,* 19(1), 19-49.

Lindsay, S., Cancelliere, S. (2018). A model for developing disability confidence. *Disabil Rehabil*., 40(18):2122-2130.

McGinley, C., and Dong, H. (2011) Designing with Information and Empathy: Delivering Human Information to Designers*. The Design Journal,* 14:2, 187-206,

National Federation of the Blind. (2016). Blindness Statistics. Retrieved from: https://nfb.org/resources/blindness-statistics. Last retrieved: April 2019.

OCADU (2019). Degree Completion. Retrieved March 11, 2019 from: https://www.ocadu.ca/alumni/lifelong-learning/degree-completion.htm.

Pahl, G., Beitz, W., Feldhusen, J., and Grote, K.-H. (2007*). Engineering design: A systematic approach, (3rd ed.).* London: Springer-Verlag

Pusey, J. (October. 8, 2008) University employee finds light in the darkness. Iowa State Times. Retrieved from: http://www.iowastatedaily.com/news/university-employee-finds-light-in-the-darkness/article_53c3a8a1-3be0-5a78-bf68-47f2c433b4cb.html

University of Washington, (2015). Making a Makerspace? Guidelines for Accessibility and Universal Design. Retrieved From: https://www.washington.edu/doit/making-makerspace-guidelines-accessibility-and-universal-design

Utah State Division of Services for the Blind and Visually Impaired. Services Offered. Retrieved on 2 May 2019. Retrieved from https://jobs.utah.gov/usor

Vasiliauskas, Vidas (2014). "Developing agile project task and team management practices". Eylean. Retrieved from: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKEwiS4ePJuLfhAhUHRqwKHYdHAykQFjAAegQIARAC&url=https%3A%2F%2Fwww.eylean.com%2Fen%2FPublications%2FDownloadPublication%2F3443705e-1697-4557-8327-ff8644fab40b%3Fname%3DWhitepaper---Developing-agile-project-task-and-team-management-practices&usg=AOvVaw1rZcKkuaSNSzuTsD5KpgnG

Visser, W. (2010). Simon: Design as a problem-solving activity. *Collection* (2). 11-16. Retrieved from: https://hal.inria.fr/inria-00565886v2/document

Visser, W. (2009). Design: one, but in different forms. *Design Studies*, 30(3). 187-223. Retrieved from linkinghub.elsevier.com/retrieve/pii/S0142694X08001051

Watson, A. (2015). Design Thinking for Life. *Art Education.* 68(3). 12-18.

Weinschenk, S. (2011). *100 Things Every Designer Needs To Know About People.* London: Pearson Education

Willkomm, T. (2005). *Make a Difference Today! Assistive Technology Solutions in Minutes*. ATECH Services.

ww4b.org. (2019) *Manual for Blind Woodworkers.* Retrieved from: http://ww4b.org/ww4b_manual/

Vande Zande, R. (2011). “NAEA News April 2011.” *NAEA News,* 53:2, 1-20. Retrieved from: 10.1080/01606395.2011.11518698

Visionaware. (2019). *Gil's Guide to Woodworking.* Retrieved from: https://www.visionaware.org/info/everyday-living/home-repairs/gils-guide-to-woodworking/123

Yakman, G. (2010). STEAM: A framework for teaching across the disciplines. In Hwang, J., Taylor, J. Stemming on STEM: A STEM Education Framework for Students with Disabilities. *Journal of Science Education for Students With Disabilities,* 19(1), 19-49.

Appendix A - Coding

This appendix documents the coding process that suggested the categorization of woodshop practices into teaching principles. In these tables, regularly observed behaviours, or codes, are on the left column, with specific examples in the centre column, and the number of occurrences on the right column. Codes with enough in common were brought together into categories, and those categories were named after the teaching principle that described the codes that comprised them. Categories are written at the top of the table in bold (eg: **Chunking**). Photos and videos are referenced by 4-digit filename, and a time code for videos, and can be found at http://ericmforest.com/school/mrp/eric/.

Chunking (breaking lessons and tasks into manageable pieces)		
The general method of organization was to break the creation of the candy dispenser into roughly 17 chunks, or steps, of work	1) Plane rough wood to thickness 2) Joint one edge square 3) Smooth on drum sander 4) Rip boards to width on table saw (about 3.25 inch) 5) Cut boards into sections for the body on mitre saw (about 5 inches each) 6) Hole saw (2.5 inch) through the centre of the top layer of the body, and hole	17

saw (2.5 inch) offset through the middle layer. Set plug aside

7) Drill a ¼ hole into the middle of the bottom layer along the top edge, so that it is centered beneath the centre of the offset hole in the middle section
8) Route bevel into the hole in the top and middle sections
9) Turn plug into a wheel on the lathe
10) Glue all 3 layers together and clamp
11) Sand body
12) Route edges smooth with ¼-inch roundover bit
13) Cut ¼ inch aluminum pegs with hacksaw
14) Apply oil finish
15) Glue ¼ aluminum peg into bottom section so that is becomes an axle for the wheel in the middle
16) Glue mason jar lid-ring into top section
17) Fill mason jar with candy and screw into lid

Individual chunks are transferable to other projects	Students learned how to take rough wood to workable size, independent of the specifics of this project (Appendix F)	1
Explicit Instructor mention of chunking in survey responses	“Chunking is probably one of things I am best at. I give people a vague overall and then walk them through the step” “for learners it can simplify the process” “This [chunking] can let more than one tool be in use at a time” “If I'm building something and it has parts that are the same. For example a shelf with two sides and a back all the same length. I'll cut them all at the same time, because you can never set a saw exactly the way it was before.”	4

Constraint (how are tools used safety)		
Jigs that constrain the workpiece in place, allowing students to focus on learning the tool operation, while still having a consistent output	Jigs used on 3 drill press functions and one router function Router table: 7606, 7994, 7995 One student teaching a jig to another: “and it stops there, and then you move it forward and back to the left. And then you go up the other way, and again, it stop when the…when the…when the stop hits the back. And they you go back up.” 7606 (1:40)	7

	Drill Presses, 7740-43	
Guides, fences, and stops that constrain the user to move the workpiece into the tool accurately (fences, stop blocks)	Featherboard on table saw Rip fence: “I keep my hands on the fence” 7900 (4:22) Video of student adjusting fence at 8071 (1:07) I make sure I am pushing it [the wood] against the fence. 7900 (3:56) Drill press depth stop: 7815 Chop saw stop block (Appendix F) “And then he set these stops that are already in place for us” 7873 (1:10) On setting a chisel edge on a grinder: “So is that to say, this plate here [the grinder fence], if you loosen it” … “you can move those things everywhere” … “you can change its angle!” 7818 (8:50)	8
Explicit Instructor mention of constraints in survey responses	“many tools also have stops.” “this is good for a first timer but can also put a limit on the learning level” “[good for] repetitious types of work”	3

Piloting (testing a class before delivering it)		
Piloting by preparing shop layout and tools in advance	“That was a box [placed there] to catch the pieces” 7574 (1:20)	7

	"We've set up a couple lathes" 7576 (1:36) Preparation of jigs and stops: 3 drill press jigs 7740, 7815, 1 router jig 7994 1 chop saw stop (Appendix F) "I try to make sure everything is set up and working, because you can't people waiting for the instructor to figure out the machines" (Appendix F)	
Instructor mention of piloting or similar in survey responses	"We have projects that we already know work. But we try to plan new ones by doing dry runs" "some kind of testing is needed to be sure if it works" "I have to do this because I'm stepping into a shop I haven't been to in a while"	6

	“coming form production backgrounds, this is just good common practice” “we do not pilot very much any more because we have some proven projects” “if I’m going to be teaching a certain project I want to go to each machine and make sure it is in the same ballpark. I need to make sure what I am going to be teaching in possible, without anyone watching me go through 20-25 minutes of setting up. like making sure a power point is ready to go. be ready for the students.”	
	Hierarchy (how a project’s conceptualization is communicated)	
Hierarchy as a means of planning delivered by speech, touch, or both	“A blind person has no use for printed plans” - George Wurtzel (Appendix F). On day 1 the instructor passed around the completed project and described it makeup hierarchically: entire thing made up of jar and	4

	body. Jar is made of two parts. Body is made of 3 parts, inside which is a wheel, inside which is a pin (Appendix F). This was repeated on day 2, with all the parts laid out individually. Hierarchy diagram (Appendix F)	
Instructor reaction to the concept of hierarchy in survey responses	“we need to bypass the blueprint process. this starts with giving them a basic, rough concept. it makes it easier to go where they are going. a mental map is helpful, but if you can touch it makes all the difference.” “Blueprints dont work” “students should be able to hold parts because they aren't obvious from the finished product” “comes back to chunking. show them what the goal and the outcomes will be, broken	8

	down into manageable steps to reach the goal” “First thing they'd do is a couple of different things. They give you a little piece of wood and mark out a grid with a rotomatic and drill out holes. Using a hand saw, a square, and an awl, I had to cut off the 2x4 to learn to cut a straight line. Baby steps.” “for everyone to make the same thing, they need to know what they are making.” “This [hierarchy] is great” “plans are not accessible, so some way to relate the project has to happen” “trying to take a thought bubble and put it into their hands”	

	Confirmation (how to be certain of what you can see)	

Two step safety switches require a user to make more deliberate choices to slow down and confirm they really want to turn on the machine.	Switches mounted on table saw, lathe, jointer, belt sander, planer. Images 8024, 8027. Appendix F.	5
Audio confirmation is sought when turning on machine where multiple users are/may be present	“Should I turn it on? Ok, I’m turning it on” 7779 (1:35) “Saw coming on” 8070 (0:55) “Router coming on” 7761 (0:00) Appendix F under table saw. “I'm going to turn it on.” “ok.” 7818 (3:32)	4
Confirming safety by referencing the user’s hand relative to the blade or tool. For example, encountering a specific component of a tool (where two surfaces meet, a bump, a knob, a texture) might indicate it is not safe to move the hands further.	Video of student feeling for confirmation on jointer, 8038 (2:23, 2:56? 3:10?). Appendix F under “belt sander.” Instructor using featherboard to confirm hands are in a safe position. 8070 (0:54) “I keep my hands on the fence” 7900 (4:22) “I like to set this right here. Over here. Then I feed...I feed...I put my hand here and I make sure I am pushing it [the wood] against the fence. 7900 (3:43) “When the end of the board gets to here [indicates with hands] I grab this [grabs push stick” 7900 (4:10) “Never use that [push stick] until the end of this board gets on the table” (instructor can be seen placing student’s hand in position. 8070 (0:27) “That’s just your ‘Im getting close,’ you know? And when this hands coming up here and you say ‘Ah! That’s the sport for me to	9

	stop’” 8071 (2:20)	
Confirming tool operation with sound. For example, change in sound identifies pressure being applied (too much, not enough) and location of application (on a flat edge, on a corner).	Appendix F under wheel/lathe “Hear the sound change?” 7779 (1:48) Disc sander corner shape rounding by sound 7724 Disc Sander pressure by sound (knows to release pressure when sounds gets too deep) 7730 Appendix F under router “Sound indicates when through to sacrificial piece.” Appendix F under drill press	5
Confirming operations with smell	Nearly all tools make a burning smell if used aggressively or improperly. Smell can confirm Wood type and dryness. Burning smell can also indicate dull or worn out tools. Suspecting worn sandpaper, Brian checks workpiece for burning 7730 (0:13)	3
Confirming tool operations with touch	Student feels out path of wood on table saw prior to running it 7900 “And then i put my hand right here” 7900 (3:50) 8070 (0:27) Use the push stick “when the end of this board gets on the table” 8070 (0:39) 8071 (02:22) Pull drill press down and verify target (Appendix F under drill press) Pull chop saw down and verify target (Appendix F under drill press)	8

	Confirming lathe speed before applying tool by feeling the chuck 7762 (0:30) “Feel the chips” to confirm chisel or gouge pressure coming off lathe 7779 (1:53) Instructor moves hands to locations: “There is the wheel. There is the water container.” 7818 (3:23)	

Flexibility / Useability Tradeoff (single function tools are preferred for learning)		
Choosing more single use tools instead less multi-use tools to complete chunks of work	“The Felder rarely gets used. Set up and breakdown takes too long, and set ups will never be the same, you will never be able to make the exact same cut twice” - Instructors (Appendix F) Crosscut sled present but not used. Chop saw preferred (Appendix F) Three drill presses used, rather than changing the bit three time in one press 7740, 7570	7

	Three routing operations done with three routers, rather than changing the bit on 3 routers 7558, 7719, 7914	
Instructor reaction to the concept of flexibility vs. usability in survey responses	"My last purchase was a panel saw. I don't know how I lived without it." (Panel saw is a very specific-use tool). "selecting the right tool is a complicated process where there is a lot to consider" "those multi-tool things are boat anchors. one tool to do one job is always better than one tool that does many jobs." "in cases where a more complicated tool is necessary there is no choice" "having come from an industrial background, sometimes you do things in two steps, just because it does keep it simple, you could do it in one step on a tool, but then you'd have to change out the tool" "sometimes you might pick a harder tool juts to teach its use, or to teach its flexibility. But	8

	it does make sense that changing up a tool between steps is bad because you can never set a tool to make the exact same cut twice” “I tend to have lots tools. Panel saw, drill press, 20in planer, bandsaw, jointer, router table.” “multiple tools were made for people with small shops and a lot of imagination. they require lots of planning and are only good for someone making a big project. i've seen devices that do multiple stuff, but you can't really teach them because it will be complicated. diving into a mainframe before knowing what a computer is. boring setup times while student watches. creating lineups. like a universal gym with a lineup.”	

Modularity		
The project’s parts are modular, that is, specific parts are interchangeable between one person’s project and another	“Can I have everyone’s attention. We’ve now got enough part for everyone to glue up a	10

	couple...uhm...jelly bean machines” 7576 (0:57) “We’ve set up a couple lathes, so that we can have a couple of people turning lathes at the same time” 7576 (1:36) Images and videos showing stacks of modular parts: 7873, 8019, 7617, 7578, 7849, 7790 Instructor explained how 3 layers cut from same piece makes it modular (Appendix F) Project allowed for repeating each step multiple times	
Instructor reaction to the concept of modularity in survey responses	“You gotta think about where people are at with their learning process. I do modularity with things I build.” “it's more about getting people working together”	8

“we don't always do this. it depends on where we want to get to with the group, where we want to take them.”

“assembly line production. setting up all the steps, and it doesn't matter who runs which”

“We are doing that right now with the cub scouts making birdhouses. These are third graders. We are showing the kids to assemble them. We'll show them how we cut the wood and they are going to put them all together. This their age its a great way to introduce them.:

“If I'm building something and it has parts that are the same. For example a shelf with two sides and a back all the same length. I'll cut them all at the same time, because you can never set a saw exactly the way it was before.”

“the challenge is getting everyone's work to line up and fit together. But this is also a measure of how much students are learning.”

“say we need to teach chop saw. this is good to teach a chop saw, because a student can learn what it's like to 1, 2....4, 5 cuts. and they learn what it's like to do a lot..."Why don't you get 8 1 ft sections from an 8 foot

	board?" you walk away from using it once, all of that is lost. modularity lets you repeat and develop a mental system in your head. it can also help to serve other users who are not yet ready to use the big machines, because they can assemble the parts.”	

	Progressive Disclosure (knowledge is disseminated at an appropriate pace)	
Students learn one tool before moving on to another	Students had to opportunity to repeat each chunk of work multiple times, until they were comfortable with it, before moving to the next (Appendix F) “Each student will learn a tool from an instructor. Then they will repeat that until they get good at it and feel comfortable before moving on” (Appendix F) Students mastered each chunk of work well enough to teach it to another 7606 (1:07), 7953	4

Survey Responses	"it is too much for someone new to remember an entire project. [from start to finish]" "building up the knowledge is important" "woodworking is a big field and it can be a lot to jump in" "I am really big on this. I make sure everything is bite sized. also students teaching students really reinforces" "all i can say is it takes time. I've been doing it since 7th grade. I did it in high school shop, auto body, upholstery. And all of that knowledge applies. With auto body if you don't fix it in the bottom its gonna show at the top. It's the same thing with wood." "we start with hand tools and work our way into power tools."	7

	"getting the students to teach each other is key. once a student teaches another what they learned, then they really learned what they learned. it's like doing a presentation. its combines repetition and teaching."	

Iteration (allow for errors by facilitating error correction)		
Working and reworking a piece until it is "right"	"Try another one!" 7575 (0:03) Student checking depth of wheel on lathe with finger 7597 (0:18) and referring to completed ones 7759, 7798 Student sneaking up on a tool setting: "Should I still be turning it?" "Is it still moving?" 7888 (0:43) Student finessing glue-up 7610	4
Survey responses to use of iteration	"lots of things require some kind of trial and error. especially when setting up jigs"	7

	“i've done lathe work. I totally appreciate what they are doing.”	
	“what other choice is there?”	
	“this is pretty well how it works”	
	“it is good to have one element that is different. Some parts of the project the student is in charge. like this one”	
	“whenever an error is made, and an adjustment follows”	
	“here's an example, I used to make another kind of candy dispensers but with a knob. they would. turn an 18-inch piece on a lathe into a ball or an oval shape on the one end. first we'd do it together, and we'd go down to the end making more and more balls. by the last one it was always so good, and they tried	

	all the tools and learned. and the extra balls were used for other modular projects, for students who can't use the lathe (children). but it allows for repetition.” “I individually modify, on the fly continually, each lesson for each student.”	

	Control (teacher and student control over environment and learning)	
Teacher controlled learning	The product (candy dispenser) and the means of making it was decided by the instructors	1
Student controlled learning	Student brought his own special tools to study with the instructors 7797 (0:20) Student being taught how to pattern (make a plan) so they can create their own projects down the road 8035 Students encouraged to share “what I want to learn” during roundtable introductions.	8

	Instructors did come back to accommodate student requests (Appendix F) Students asked to learn chisel sharpening (not part of the instructor's project) 7818 Student building a box (not part of the instructor's project) 7958 Students exploring a tool outside the prescribed learning path 7604 Student altered the plan that the instructor provided 7920 Student shown multiple ways of doing some things, eg, measuring each cut or setting up a stop block on chop saw (Appendix F).	
Survey respondents comments on control	"not too much [instructor] control. just enough to make sure students learn"	7

	"If the student is unfamiliar with the shop then there is orientation that needs to happen." "look for key indicators. when I get a new students, ill spend time with him/her watching them twitch while all sorts of noises are going on. we'll try a tool and they are white knuckling it, I know that student is not ready. at some point the student will relax, talk, use complete sentences. Then I know we can more forward. Most of it is in how they are talking to you, and if someone is scared you can read them." "a lot of the students are not having wood shops just because they took a woodworking course. but I do like to tools people will use." "I individually modify, on the fly continually, each lesson for each student."	

	"I take a new students around and show them things and hand tools for two week when they start. I get two know them. I learn them, but they learn as well, touching all these things, sandpaper, grit, 100, 400, 800" "it is important to get another class for blind students to take."	

Appendix B - Videos

Videos of blind woodworkers using the principles can be seen at

http://www.blindwoodworking.club.

Appendix C - Member Check

This document contains the survey and responses from the member check. The PDF is 250 megabytes. http://ericmforest.com/school/mrp/eric/survey.pdf

Appendix D - Interview Notes

These interview notes were taken when interviewing design instructors from mainstream colleges and universities. http://ericmforest.com/school/mrp/eric/interviews/

Appendix F - Notes from Woodworking Course

These notes were taken while participating in the woodworking course in Chapter 3.

http://ericmforest.com/school/mrp/eric/notes/

Appendix G - Glossary of Terms

Chop saw	Sometimes called a mitre saw or a crosscut saw. Chop saws typically have circular blades that are 8, 10, or 12 inches in diameter and powered. The blade is on a hinge, above the wood, and a handle pulls the down into the wood. The grain direction of the wood, and therefore its longer edge, is normally perpendicular to the blade, such that the blade cuts "across" the grain. Chop saws are often used to cut long, narrow pieces into shorter ones.
Click Rule	A tactile ruler very similar in operation to a depth gauge. A tube about 7 inches long contains a graduated rod about 7 inches long. The graduated rod can be extended from the tube, and by counting the tactile graduation from the mouth of the rod (where there is a fence) the user can take a measurement. Extensions exist to make the rod as long as required.
Drill Press	The drill press is a drill mounted on a pole and facing downwards. It can be free standing or table mounted, and the interchangeable drill bits are moved downward into the workpiece by means of a lever on the side. The workpiece sits on a table of varying size by usually about a foot square, under the drill bit, that is also mounted to the pole.
Feather board	A feather board is a safety device use in woodworking, temporarily affixed to the surface of a tool, such as a table saw. The feather board provides lateral pressure into the workpiece, securing it in relation to the blade and the fence, such that its path is safety restricted along an intended course, but no so constrained that it binds and cannot move.
Fence	A fence is a stop or a guide on a tool, against which the workpiece can register or align. To make long cuts on a table saw, a fence locked parallel to the saw blade provides a stable guide against which the board can be pressed laterally while it is driven forward. To make mitre cuts on a table saw, the fence can be placed behind the wood, ensuring it is pressed into the blade at the correct angle. A fence is a constraint.
Jig	A jig is any construction that guides a tool or a workpiece along an intended path, usually to facilitate difficult or repetitive work. Jigs vary widely in complexity. A very simple jig might be made of two scrap pieces of wood, clamped to a drill press table. When the workpiece is slid against the two pieces of scrap, they locate it into position under the drill bit. Complex jigs, such as those used in joinery, are manufactured by specialty producers and can cost hundreds or thousands of dollars. A jig is a form of constraint.
Jointer	Jointers are used for squaring the edges of wood.
Lathe	Lathes are tools used to cut products with rotational symmetry, by spinning them along a horizontal axis and allowing the user to force a cutting chisel into them. Examples of objects produced on lathes are wheels, spindles, or bowls.
Mortisor	Mortisors are used in joinery to machine square holes (drill only make round holes).
Planer	Planers are used for squaring the surface of wood

Product	In manufacturing and woodworking, "the product" refers to the finished object, in a specific sense (such as a brand of cabinet door) or a general sense (an entire kitchen and all the cabinets in it). Product can also refer to materials, like plywood or stain. In this paper "product" and "the product" refers to the finished object, the candy dispenser, being made by the students in Chapter 3.
Rip	A long cut down a board or sheet good, normally with the grain.
Rough wood	Wood that has come off the mill and received no further processing. After the tree is felled (cut down), a very large saw with very large teeth that leaves visible marks cuts it into transportable boards. These are generally unsuited for immediate use and require smoothing and squaring.
Router	A rotary power tool. It can be mounted underneath a table, with the bit protruding from the top and the wood drawn across it, or handheld, such that the tool moves across the wood. Routers are typically used to cut decorative bevels, joinery, or inlay.
Sizing-up	Rough wood is not immediately workable in many cases. It needs to be made the right thickness (thickened), smoothed, flattened (to remove warping and cupping caused during the drying process), and squared on at least one edge so it can be fed along a tool fence. This process of making the wood "workable" is called sizing-up.
Squaring	Sometimes phrased as "squaring-up." A large proportion of carpentry (but not all) begins with rectangular pieces of wood. Square wood will measure 90 degrees at all corners and vertices, in three dimensions, and have no cupping, twisting, or bowing.
Table Saw	A table with a powered circular saw blade, typically 10 or 12 inches in diameter, that protrudes from the top. Wood is slid over the table, into the blade, usually to make long cuts called rips.