Anyone Can Learn Universal Design: An Interdisciplinary Course Centered Around Blindness and Visual Impairment

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Abstract

Courses at the postsecondary level continue to rely heavily on visual material that is accessible only to fully or partially sighted students. Tactile graphics work for many pedagogical purposes, but in some cases are insufficient; other information and concepts may be better conveyed through haptic exploration of 3D printed objects. However, there is a dearth of 3D-printable open educational resources for college-level content. To address this need while simultaneously teaching students about accessibility and universal design, we designed and taught an experimental course in which students (a) learned about disability in general and blindness in particular (including history and advocacy); (b) explored technology used by people with visual impairment; (c) heard from many blind voices, including guest experts and community members; (d) studied universal design; and (e) designed 3D-printable educational tactile models in collaboration with blind community members. By the end, students demonstrated significantly less bias and more positive attitudes about blindness and people with visual impairment, and were more confident with accessibility, universal design, and assistive technology. We believe this course can serve as a model for similar courses elsewhere as a strategy to teach students from any major about disability, accessibility, and universal design.

Keywords: universal design, accessibility, blindness, OER, 3D printing

Postsecondary instructors who receive little to no pedagogical training related to disability, accessibility, or universal design may, as a result, unintentionally create learning barriers for their students. While some accommodations to remove barriers and provide equitable educational access are simple (e.g., additional time for exams), other accommodations are much more complicated (e.g., remediating inaccessible documents).

Blind and partially sighted students in particular are often denied the same educational resources as their sighted peers because many disciplines make heavy use of graphics, pictures, charts, animations, and other visuals (Bell & Silverman, 2019). It can be challenging for instructors to find or create non-visual ways to fully convey the same information, such as high-quality tactile graphics or hands-on 3D models. However, if such pedagogical materials already existed for a wide variety of courses and were released online as open educational resources (OER), then instructors and/or disability services staff could access open databases of these materials and print them at negligible cost using tactile graphic printers or 3D printers.

In this paper we describe a course that may serve as a model for how to address the need for such OER in a scalable way. The course was designed to be interdisciplinary, showing that students from any major can be taught about disability and universal design in a way that has a lasting influence on their own perspective and behavior, in addition to providing valuable real-world, project-based experience that contributes toward a genuine need.

As an aside, we use the terms blind, blindness, and blind people throughout this paper in a broad and inclusive manner (i.e., this definition includes people with some amount of vision), though there is no universally accepted definition of those terms, nor for related terms like visually impaired, partially sighted, low vision, and so on. For example, Kenneth Jernigan, long-time president of the National Federation of the

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Blind, famously eschewed legal and ophthalmologic definitions of blindness (e.g., less than 20/200 acuity after correction or very small field of vision) for a more functional and sociological definition:

> One is blind to the extent that the individual must devise alternative techniques to do efficiently those things which he would do if he had [ophthalmologically] normal vision. An individual may properly be said to be “blind” or a “blind person” when he has to devise so many alternative techniques--that is, if he is to function efficiently--that his pattern of daily living is substantially altered. [...] I believe that the complex distinctions which are often made between those who have partial sight and those who are totally blind [...] are largely meaningless. In fact, they are often harmful since they place the wrong emphasis on blindness and its problems. Perhaps the greatest danger in the field of work for the blind today is the tendency to be hypnotized by jargon. (Jernigan, 2005, p. 1)

Whether using the terms blind, visually impaired, or partially sighted, the important thing for the purposes of this paper is that non-visual learning material is absolutely essential for many students but can also be beneficial for all other students (including those with various types and amounts of vision).

Summary of Relevant Literature

While textual material is easily converted to another modality using text-to-speech screen reader programs, the ubiquity of other non-text visual material in postsecondary classrooms is a common barrier for blind students, who in turn are less likely than their peers to complete a degree (Erickson et al., 2022). In some cases, describing an image in words (i.e., “alt text”) may be sufficient to convey essential information. However, for a lot of material that is normally presented visually, the best way to learn a concept, process data, or develop a mental model is to explore a tactile representation (Jones & Broadwell, 2008). Tactile graphics can be created with a Braille embosser, thermoform plastic from a mold, or thermal capsule paper that creates raised lines or bumps when passed through a special printer (this last solution being the cheapest and fastest).

However, in many cases, visuals at the postsecondary level have information density or complexity that makes tactile graphics an inelegant or incomplete solution (i.e., a single diagram may need to be manually converted into many sub-graphics, say, to overcome the limitations of detail for the modality of touch; Braille Authority of North America and Canadian Braille Authority, 2011). Very simple color can be represented with texture, but with many different textures and line types it may be hard to clearly convey the same information as the visual modality allows. Certainly it is not as easy as automated conversion of a picture file to a tactile printer file by a computer program.

In many cases, a better way to convey information non-visually to help students understand and create mental models is hands-on exploration of 3D objects (Jones & Broadwell, 2008; Klatsky & Lederman, 2011). Indeed, basic perceptual research has shown that 2D tactile graphics made with raised lines are often inferior to 3D objects (Lederman et al., 1990; Loomis, 1981; Shimizu et al., 1993). As Ballesteros and colleagues (1997) point out, “Raised-line stimuli reduce the effectiveness of the [tactile] system, forcing it to use only a very small part of its encoding capability, and thereby limit its performance” (p. 49).

However, while proprietary hands-on 3D models are common in some disciplines (e.g., a plastic brain or heart to teach anatomy, stick-and-ball models in chemistry), these do not exist for most of the visually-presented material in any course, and in many cases these are proprietary, expensive, use color, or cannot be adapted or improved on by instructors (Chakraborty & Zuckerman, 2013; Griffith et al., 2016; Groenendyk, 2016).

On the other hand, 3D printing has become relatively cheap and simple at the consumer level and most campuses either have a 3D printer or are near a public library or makerspace that offers 3D printer access (Ford & Minshall, 2019). With 3D printing, the design for a hands-on educational model can be shared as an online file and then printed from anywhere. In many cases, these are shared on a general purpose open database for 3D designs (e.g., Thingiverse.com) or a specialized database (e.g., National Institute of Health’s 3D Print Exchange; Coakley et al., 2014) under a Creative Commons license that allows freely using, sharing, and altering or improving the design. Groenendyk’s (2016) cataloging of educational 3D printable designs on the internet found that they overwhelmingly tend to be shared for free. Such freely shared and remixable designs can be considered open educational resources (OER), meaning they are educational materials under an open copyright license or in the public domain (Wiley et al., 2014).

Metalibraries (e.g., BTactile.com) allow searching across many different databases, although most designs are for basic objects (e.g., a lion, a soccer ball, the Eiffel Tower) or simple concepts relevant to primary and secondary school. A big challenge going forward will be creating and iterating open access 3D-printable files at scale for the wide variety of courses found in the many disciplines of postsecondary education. A solution is needed that scales up this design process in a distributed manner. To the extent that some disciplines have started using 3D printed artifacts for teaching (e.g., Rossi et al., 2015), there are currently far too few, and researchers have called for the creation of more extensive open-access libraries of 3D models (Horowitz & Schultz, 2014; Groenendyk, 2016). Below we describe our model for an innovative solution: to have groups of students create (or test and improve) 3D-printable hands-on educational models and release them freely as OER online.

Notably, such design work cannot be done well without the appropriate background knowledge and context. For example, students may not be familiar with the wide diversity of visual function and impairment and may see blindness as a binary (sighted vs. no vision; Jernigan, 2005), so some basic information about the visual system and visual impairment is important.

Students may also need to learn how processing and learning work differently in the tactile channel than they do in the visual channel. Vision is more holistic and parallel, while haptic exploration with touch is sequential, slower, and taxes working memory to a greater degree (Ballesteros et al., 2005). Visuals used in postsecondary curricula often utilize depth, perspective, and other three-dimensional visual cues and these are simply not interpreted in the same way when presented in the tactile modality (Lederman et al., 1990; Wijntjes et al., 2008). Thus, converting a visual representation of a 3D scene or object into a 2D tactile graphic fails when that visual representation relies on cues that won't be interpreted the same way by touch (Klatsky & Lederman, 2011). Designing tactile educational objects requires some understanding of tactile learning (Pawluk et al., 2015).

Additional context comes from understanding accessibility, the extent to which objects, services, or environments can be accessed (specifically by those with disabilities). For example, ramps, elevators, and curb cuts in sidewalks all provide users of wheelchairs access to environments they otherwise would have trouble accessing. Braille signage, tactile maps, and audio signals at pedestrian crossings all allow those with visual impairments to navigate new spaces. To design for accessibility is to remove barriers and increase access, not just for physical mobility, but for employment, education, voting, housing, access to private businesses, and so on (Karellou, 2019; Syed et al., 2022; Oishi et al., 2010).

Designing well for people with disabilities also means understanding the kinds of technology used by people with disabilities (assistive technology) to accomplish functions that would otherwise be challenging or impossible. For example, many blind people use white-tipped canes for mobility, refreshable Braille displays to type and read Braille, and screen readers to convert digital text to synthesized speech (Hersh & Johnson, 2008). Likewise, magnification devices may make visual material originally designed for high-acuity vision (e.g., a handout printed with typical font size) accessible to those with less visual acuity.

While some of these technologies are specifically adapted to the needs of one specific user group (adaptive technology, a subset of assistive technology), many of these technologies are helpful not just to those with disabilities but to everyone (Hersh & Johnson, 2008). Tactile pavement provides cues alerting people to approaching streets, train tracks, or surface hazards; this benefits people who are blind or visually impaired but also sighted walkers who are distracted in conversation or on their phone. Text-to-speech programs and audiobooks are popular with sighted people as well as those with visual impairments. Captions and subtitles benefit not just Deaf and hard-of-hearing individuals, but those learning a language, those with learning or auditory processing differences, viewers in distracting or loud environments, and so on. Curb cuts benefit people pushing baby strollers or rolling luggage in addition to those using wheelchairs. Good design benefits everyone (Oishi et al., 2010).

Universal design (UD) has been defined by Ronald Mace as “the design of products and environments usable by all people, to the greatest extent possible, without the need for adaptation or specialized design” (The Center for Universal Design, 2008). This means following design principles such as equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance for error, low physical effort, and appropriate size and space for use. UD assumes that designers are better off integrating human change and range into design from the start instead of isolating less-common ability ranges as “disability”. By adopting a universal design framework, students creating educational materials with the goal of making visually-presented material accessible in the tactile modality will provide benefits not just blind and visually impaired students, but potentially all students (Burgstahler & Cory, 2008; Estevez, et al., 2010; Reiner, 2008).

Finally, designing well for people with disabilities means listening to their voices, understanding something about disability history and advocacy, and including people with disabilities in the design process (Mankoff et al., 2010; Spiel et al., 2020). In a postsecondary course, this could include hearing directly from blind and visually impaired voices (as guest speakers or through podcasts, readings, and videos) and via collaborative interactions with blind community members.

An added benefit of an interdisciplinary version of such a course would be to weave disability, accessibility, and universal design into the wider postsecondary curriculum, not just in the handful of disciplines it more commonly shows up in (e.g., computer science, education, disability studies, engineering, design). Students in general go on to join a diverse workforce where they will interact with disabled colleagues, supervisors, and clients, create and carry out processes, and make products and render services. Educating students about disability may thus have far-reaching downstream effects that increase equity in the wider world. Additionally, employers increasingly seek candidates with accessibility skills (PEAT, 2018), so these skills make for more competitive graduates as well.

Setting and Participant Demographics

Our course was an experimental interdisciplinary course at a state university in the Northwestern United States with around 20,000 undergraduates enrolled (Carnegie classification: doctoral granting, high research activity), though such a course would likely work just as well at a community college, liberal arts college, or other institution. The course was team-taught by a faculty member in Psychology and a faculty member in the library; it was cross-listed by the registrar as an offering through the Psychology Department and through the College of Innovation and Design and was open to anyone. Students were made aware of the course through fliers posted around campus and emails with a description of the course sent out to advisors around the university. Seventeen undergraduates enrolled (8 male, 9 female; age not collected), and they represented many majors (biology, psychology, communication, health science, graphic design, criminal justice, English, and so on). The course was a standard 3-credit hour class that met twice a week for 75 minutes across a 15-week semester.

We collaborated with the campus' Educational Access Center while designing the course and to secure a guest speaker. We also collaborated with the state's Commission for the Blind and Visually Impaired, both to bring in guest speakers and experts and so students could meet and collaborate directly with blind community members as part of their team projects to create new 3D-printable designs. Community members were recruited through word of mouth by Commission staff. Finally, we collaborated with the makerspace in our campus' library to assist students with 3D printing their designs.

Depiction of the Problem

As mentioned above, there is currently a dearth of resources when it comes to tactile graphics and especially to 3D-printable models covering postsecondary educational material in many fields of study. Of the content that does currently exist (usually only for simple concepts), it is often made by hobbyists rather than in an academic realm, and designs may not be informed by knowledge of disability or UD. Thus, a scalable solution is needed where, say, college students who have taken a thermodynamics course or a historical geography course learn enough about UD to create accessible 3D models (or tactile graphics, where appropriate) for those subjects.

Another problem addressed by a course like ours is the distinct shortage of existing accessibility training in postsecondary curricula. Even in computer science, most faculty do not teach accessibility in their courses (Shinohara et al., 2018) and fewer than 3% of engineering and computing course descriptions mention anything related to accessibility (Teach Access, 2018). Likewise, in the field of education, undergraduates studying to become teachers generally feel unprepared to teach students with disabilities (Carroll et al., 2003). In many other majors, these topics come up even less, leaving students unprepared to address disabling barriers in their future lives and careers.

Description of Practice

We believe that a course like this, at its heart, should come at the problems described above from at least two angles: (a) the students learn about disability and accessibility, specifically as it relates to blindness and visual impairment, and (b) the students learn about design and 3D printing in general and universal design in particular. To address the first, students in our course learned and read about the following:

- Definitions and models of disability (e.g., the moral/religious model, the tragedy/charity model, the medical model, the social model, the cultural model, universalism)
- Visual impairment and blindness (including cultural constructions of blindness)
- Disability rights and advocacy (including relevant history and law such as the Inde-

pendent Living Movement, the Architectural Barriers Act of 1968, the Rehabilitation Act of 1973, the Capitol Crawl, the Americans with Disabilities Act of 1990/2008, the UN Convention on the Rights of Persons with Disabilities, the history of the National Federation of the Blind, and so on)
- Assistive technology
- Perception and processing in the non-visual vs. visual modalities

Obviously, many of these topics could take up an entire postsecondary course of their own, so in some cases we focused most heavily on information most relevant to blindness and visual impairment. For example, in a reading and discussion about person-first language and person-centered language, students encountered common person-first perspectives as well as perspectives from the autism community and Deaf community, but also read a statement from the National Federation of the Blind about why they as an organization rejected person-first language. Likewise, in learning about assistive technology, most of the time was spent focusing on assistive technology designed for people with visual impairments in particular (e.g., Braille systems such as Unified English Braille, contracted Braille, and Nemeth; tactile graphics; refreshable Braille displays/notetakers; DAISY; screen readers; audio description; magnification devices; electronic eyewear; optical character recognition; machine learning and artificial intelligence-based apps; personal assistant services; white canes; smart canes; Braille signs; tactile pavement; tactile maps; mapping and GPS apps; vibrotactile wearables; and sensory substitution devices). One particular focus was on failures in past design of assistive technology when sighted people had designed for blind users without consulting with them (for example, the long history of attempts at smart canes and sensory substitution devices). Activities and assignments in the course included the following:

- Using and creating tactile graphics (including learning best practices, as well as struggling to make sense of visuals when forced to see only a tiny portion at a time, analogous to the 'fingertip window' experience of tactile graphics);
- Experiencing Braille handouts and books, as well as Braille notetakers;
- Practicing with a screen reader to successfully navigate the web;
- Analyzing textbook visuals and graphics (one chapter of any college-level textbook);
- Doing sightless classroom observations (sitting in on another course with instructor permission and spending much of it without sight of the instructor, whiteboard, or screen);
- Identifying an environment or product that fails some principles of universal design
- Creating alt text for various images (and evaluating each others' alt text for best practices);
- Filling out reflections after all readings, videos, and assignments.

Blind voices were centered in the course: Students heard from and interacted with blind guest experts (including employees of the campus Educational Access Center and the state's Commission for the Blind and Visually Impaired), watched blind vidcasters (e.g., Tommy Edison, Molly Burke, and many others), listened to blind podcasters, and read essays and speeches by blind authors and leaders (e.g., Kenneth Jernigan and other presidents of the National Federation of the Blind). The students also collaborated directly with blind and visually impaired community members to get feedback on their design ideas and iterations. Based on past research and theory (e.g., Contact Theory), we hoped that this experience–combining cooperative contact between sighted and blind individuals with information provision and education–would lead to more healthy attitudes about blindness and accessibility (Allport, 1954; Corrigan & Penn, 1999; Horne, 1988).

To accomplish the design goals of the course, students also learned about design. Specifically, they first learned the basics of design thinking and the methods popularized in the business world by design firm IDEO (Brown, 2008), as well as user-centered design (as popularized by Norman, 1988). Students then learned more deeply about universal design (described above).

Since students did not come in with extensive knowledge of 3D design and printing, we partnered with the university library's makerspace to access their 3D printers and get technical help during printing. In and out of class, students worked in teams to learn how to use a simple and free 3D design software (primarily Tinkercad, but some students explored alternative free software). In a semester-long team project using these skills, they designed and iterated 3D-printable models such as a hands-on model of stereoisomers (chemistry) or an interactive tactile histogram graph maker (introductory statistics). At the end of semester, teams presented their designs (and failed iterations) as well as testing results in an accessible (multimodal, hands-on) poster session open to a variety of stakeholders from on and off campus (including members of the blind and visually impaired community).

While 3D modeling and printing may seem like imposing skill for non-technically-inclined instructors to teach their students, the logistics are less complicated than one might expect (Stone et al., 2020). Modern software is quite intuitive and comes with extensive help in the form of tutorials, documentation, and eager help from an extensive hobbyist community. Likewise, the campus library, a local library, or a local makerspace may provide support; 3D printing has become much more commonplace in all of these locations (Scalfani & Sahib, 2013).

Evaluation of Observed Outcomes

With approval of the Institutional Review Board of the university, we collected some survey data from the students in the course. They were not asked about their own disability status, but were surveyed on how much interaction they had previously had with people who are disabled (M = 3.0, SD = 1.0 on a scale of 5 = very much to 1 = not at all) and with people who were blind or partially sighted (M = 2.3, SD = 0.9 on the same scale). We collected pre-course and immediate post-course survey data from the students and they also consented to the use of written excerpts from their coursework for this study. All 17 students consented to participate, but one did not finish part of the pre-semester survey and one did not submit the post-semester survey; their data were not included in the relevant analyses.

Students were administered a 20-item psychometrically validated measure of attitudes about blindness and blind people called the Social Responsibility About Blindness Scale (SRBS; Cronbach's α = .76; Bell & Silverman, 2011; Rowland & Bell, 2012; Stone et al., 2021). The SRBS consists of statements such as “It is irresponsible of blind people to have children” and “Blindness is just a normal characteristic like being tall or short.” By the end of the course, students showed significantly more positive attitudes about blindness (N = 15, M_{post} = 69.2, SD_{post} = 9.1, M_{pre} = 64.4, SD_{pre} = 6.8, paired $t(14) = 2.04$, $p = .030$, Cohen's d = 0.53).

They were also asked some supplemental questions (Table 1) developed by Teach Access, a non-profit organization focused on building collaborations between academia, industry, and disability advocacy organizations to address gaps in accessibility skills (teachaccess.org). Students came out of the course significantly more confident that they could give examples of inclusive or universal design, define accessibility, give examples of assistive technology, and explain accessible design guidelines (all p-values < .004, significant even after conservative Bonferroni correction; Table 1), suggesting students will be more likely to consider these aspects of accessibility in their future lives and careers. Indeed, as one student wrote in anonymous feedback during a reflection assignment: “My design work will now be filtered through accessibility guidelines/standards.” Another noted, “I now understand the things in our world need to be universally designed for everyone to use.”

Implications and Transferability

This course presents one model for successfully integrating disability, accessibility, and universal design into the postsecondary curriculum in a way that also serves the additional purpose of providing increased accessibility for future students in the form of accessible OER that benefits blind learners but also sighted learners (information presented in multiple sensory modalities helps all students develop better mental models: Reiner, 2008). Similar courses at other institutions could replicate this, having student groups design (or user test and iterate) 3D-printable models and share them freely online as OER so that they can be used widely and further improved. Alternatively, students in a course like this could design or improve tactile graphics. Previous work has found significant errors in tactile graphics meant to replace textbook visuals (Smith & Smothers, 2012), and educational visuals in many courses simply have no tactile graphic equivalent. Regardless of the specifics of such a course, the key is for student creations to be OER so that others–especially busy or technically-disinclined instructors who find themselves teaching a blind student for the first time–do not have to “reinvent the wheel,” but have access to existing well-designed learning materials.

While the course enrollment (and thus our sample size) was small and students self-selected by choosing to register for the course as an elective, our results provide a proof of concept that the model, if replicated and scaled up, could be effective for both creating much-needed OER for accessible course material and integrating disability, accessibility, and universal design into the wider postsecondary curricula. The results also suggest that students’ experience in such a course could instill lasting attitude changes about disability and accessibility. Based on social network theory, we can expect these changes to have downstream benefits that spread through the students’ future social and professional networks (Daly, 2010).

Based on our experience teaching this experimental course for the first time, we offer some suggestions about what could be done better to improve outcomes in future courses like this. First, students should col-

Table 1

Teach Access Questions

Question	Pre/Post Mdn	Wilcoxon	*p*-value
1. How confident are you that you could give an example of a type of disability?	5 / 5	z = -1.1414	0.157
2. How confident are you that you could define "accessibility" as the term relates to technology and media?	3.5 / 5	z = -2.873	0.004*
3. How confident are you that you could give an example of inclusive or universal design?	3 / 5	z = -3.370	0.001*
4. How confident are you that you could give an example of how accessible technology is used by people with disabilities?	3 / 4	z = -2.699	0.007
5. How confident are you that you could give an example of how assistive technology is used by people with disabilities?	3.5 / 5	z = -.2994	0.003*
6. How confident are you that you could give an example of a technological barrier somebody with a disability might face?	4 / 5	z = -2.373	0.018
7. How confident are you that you could define the purpose of the Americans with Disabilities Act?	3.5 / 3	z = -0.660	0.509
8. How confident are you that you could explain the Web Content Accessibility Guidelines (WCAG) (or other guidelines for accessible design and development)?	1 / 3	z = -2.914^	0.004*
9. How much interest do you have in learning more about designing and developing technologies for and with people with disabilities?	4 / 4	z = -0.905	0.366
10. How much interest do you have in pursuing a job or career in accessible technology?	3 / 3	z = -0.942	0.346
11. How much interest do you have in pursuing research in the development of accessible technologies?	3 / 4	z = -1.408	0.159
12. Have you ever used assistive technology (such as a screen reader for blind or low vision users)? [Y/N]	12.5% / 81.25%		
13. One a scale of 1-5, how familiar are you with the accessibility features built into devices (such as smartphones, computers or smart TVs)?	3 / 3	z = -1.540	0.124

Note. For questions 1-8, the scale was: 1 is not at all confident, 5 is extremely confident. For questions 9-11, the scale was: 1 is no interest, 5 is very high interest. ^ n = 15 for this question since one student left it blank. * $p < 0.0042$ (significant with Bonferroni correction for family-wise alpha of 0.05).

laborate with blind users and stakeholders as early as possible in the design process to avoid initially ideating plans that do not align with real-world needs and practices. Participatory and inclusive design practices lead to better designs (Gooda Sahib et al., 2013; Newell et al., 2011). Indeed, in a reflection at the end of our course, students gave advice such as, “Get info from actual [blind and visually impaired] people”, “Don't assume [you] know problems”, “Not everything that sounds great will be helpful”, and “You must test your product with the people you want to use it.” A course like this simply will not work well if students are not meeting and collaborating with those from the community they are designing for.

The National Federation of the Blind has chapters in all states and many localities and we suggest reaching out to an advocacy organization such as this in addition to any state agencies or commissions. Perhaps even more useful would be if campus disability services recruited any interested volunteers on campus (e.g., blind or visually impaired students currently taking college-level courses in which they might have experienced barriers from vision-centric pedagogy or a lack of hands-on learning artifacts).

For instructors or for staff at a disability services office on campus, we suggest making early contact with local makerspaces (be it on campus, at a local library, or in the community) not just for access to 3D printers, but for the community support so that students can learn and develop skills in a more realistic context than always asking the instructor for help.

Disability services staff might consider reaching out to faculty around their campus to gauge interest in teaching a course like this. The model works well as an interdisciplinary course open to all (perhaps even team-taught by instructors from different disciplines) but could also work great as a project-based course for students in design-related fields (engineering, computer science, graphic design, etc.) or in teaching-related fields (education, special education, etc.).

References

Allport, G. W. (1954). *The nature of prejudice*. Addison-Wesley.

Ballesteros, S., Manga, D., & Reales, J. M. (1997). Haptic discrimination of bilateral symmetry in 2-dimensional and 3-dimensional unfamiliar displays. *Perception and Psychophysics, 59*(1), 37-50. https://doi.org/10.3758/BF03206846

Ballesteros, S., Bardisa, D., Millar, S., & Reales, J. M. (2005). The haptic test battery: A new instrument to test tactual abilities in blind and visually impaired and sighted children. *British Journal of Visual impairment, 23*, 11-24. https://doi.org/10.1177/0264619605051717

Bell, E. C., & Silverman, A. (2011). Psychometric investigation of the Social Responsibility about Blindness Scale. *The Journal of Blindness Innovation and Research, 1*(2), 1. http://doi.org/10.5241/2F1-8

Bell, E. C., & Silverman, A. M. (2019). Access to math and science content for youth who are blind or visually impaired. *Journal of Blindness Innovation and Research, 9*(1). https://doi.org/10.5241/9-152

Braille Authority of North America, and Canadian Braille Authority. (2011). *Guidelines and standards for tactile graphics* (2010). American Printing House for the Blind.

Brown, T. (2008). Design thinking. *Harvard Business Review, 86*(6), 84-92.

Burgstahler, S. E., & Cory, R. C. (Eds.). (2008). *Universal design in higher education: From principles to practice*. Harvard Education Press.

Carroll, A., Forlin, C., & Jobling, A. (2003). The impact of teacher training in special education on the attitudes of Australian pre-service general educators towards people with disabilities. *Teacher Education Quarterly, 30*(3), 65-73.

Chakraborty, P., & Zuckerman, R. N. (2013). Course-grained, foldable, physical model of the polypeptide chain. *Proceedings of the National Academy of Sciences, 110*(33), 13368-13373. https://doi.org/10.1073/pnas.1305741110

Coakley, M. F., Hurt, D. E., Weber, N., Mtingwa, M., Fincher, E. C., Alekseyev, V., Chen, D. T., Yun, A. (2014). The NIH 3D print exchange: A public resource for bioscientific and biomedical 3D prints. *3D Printing and Additive Manufacturing, 1*, 137-140. https://doi.org/10.1089/3dp.2014.1503

Corrigan, P. W., & Penn, D. L. (1999). Lessons from social psychology on discrediting psychiatric stigma. *American Psychologist, 54*, 765-776. https://doi.org/10.1037/0003-066X.54.9.765

Daly, A. J. (2010). Mapping the terrain: Social network theory and educational change. In A. J. Daly (Ed.), *Social network theory and education change* (pp. 1-16). Harvard Education Press.

Erickson, W., Lee, C., & von Schrader, S. (2022). *Disability statistics from the 2018 American Community Survey* (ACS) [Data file]. Cornell University Employment and Disability Institute. Retrieved from http://www.disabilitystatistics.org/

Estevez, M. E., Lindgren, K. A., & Bergethon, P. R. (2010). A novel three-dimensional tool for teaching human neuroanatomy. *Anatomical Science Education, 3*(6), 309-317. https://doi.org/10.1002/ase.186

Ford, S., & Minshall, T. (2019). Where and how 3D printing is used in teaching and education. *Additive Manufacturing, 25*, 131-150. https://doi.org/10.1016/j.addma.2018.10.028

Gooda Sahib, N., Stockman, T., Tombros, A., & Metatla, O. (2013). Participatory design with blind users: A scenario-based approach. In P. Kotze, G. Marsden, G. Lindgaard, J. Wesson, & M. Winckler (Eds.), *Human Computer Interaction INTERACT 2013 Proceedings Part I* (pp. 685-701). Springer. https://doi.org/10.1007/978-3-642-40483-2_48

Griffith, K. M., Cataldo, R., & Fogerty, K. H. (2016). Do-it-yourself: 3D models of hydrogenic orbitals through 3D printing. *Journal of Chemical Education, 93*(9), 1586-1590. https://doi.org/10.1021/acs.jchemed.6b00293

Groenendyk, M. (2016). Cataloging the 3D web: The availability of educational 3D models on the internet. *Library Hi Tech, 34*(2), 239-258. https://doi.org/10.1108/LHT-09-2015-0088

Hersh, M., & Johnson, M. A. (Eds.). (2008). *Assistive technology for visually impaired and blind people.* Springer: London. http://doi.org/10.1007/978-1-84628-867-8

Horne, M. D. (1988). Modifying peer attitudes toward the handicapped: Procedures and research issues. In H. E. Yuker (Ed.), *Attitudes toward persons with disabilities* (pp. 203-222). Springer.

Horowitz, S. S., & Schultz, P. H. (2014). Printing space: Using 3D printing of digital terrain models in geosciences education and research. *Journal of Geoscience Education, 62*(1), 138-145. https://doi.org/10.5408/13-031.1

Jernigan, K. (2005). A definition of blindness. *Future Reflections, 24*(3), 1. https://nfb.org//sites/default/files/images/nfb/publications/fr/fr19/fr05si03.htm

Jones, M. G., & Broadwell, B. (2008). Visualization without vision: Students with visual impairment. In J. K. Gilbert, M. Reiner, & M. Nakhleh (Eds.), *Visualization: Theory and practice in science education* (pp. 73-84). Springer.

Karellou, J. (2019). Enabling disability in higher education: A literature review. *Journal of Disability Studies, 5*(2), 47-54.

Klatsky, R. L., & Lederman, S. J. (2011). Haptic object perception: Spatial dimensionality and relation to vision. *Philosophy Transaction of the Royal Society B, 366*, 3097-3105. https://doi.org/10.1098/rstb.2011.0153

Lederman, S. J., Kaltsky, R. L., Chataway, C., & Summers, C. (1990). Visual mediation and the haptic recognition of two-dimensional pictures of common objects. *Perception & Psychophysics, 47*, 54-64. https://doi.org/10.3758/BF03208164

Loomis, J. M. (1981). Tactile pattern perception. *Perception, 19*, 5-27.

Mankoff, J., Hayes, G. R., & Kasnitz, D. (2010). Disability studies as a source of critical inquiry for the field of assistive technology. *Proceedings of the 12th Internatinoal ACM SIGACCESS Conference on Computers and Accessibility,* 3-10. https://doi.org/10.1145/1878803.1878807

Newell, A .F., Gregor, P., Morgan, M., Pullin, G., & Macaulay, C. (2011). User-sensitive inclusive design. *Universal Access in the Information Society, 10*, 235-243. https://doi.org/10.1007/s10209-010-0203-y

Norman, D. (1988). *The design of everyday things.* Basic Books.

Oishi, M. M. K., Mitchell, I. M., & Van der Loos, H. F. M. (Eds.)(2010). *Design and use of assistive technology*. Springer.https://doi.org/10.1007/978-1-4419-7031-2

Pawluk, D. T. V., Adams, R. J., & Kitada, R. (2015). Designing haptic assistive technology for individuals who are blind or visually impaired. *IEEE Transactions on Haptics, 8*(3), 258-278.

PEAT (2018). *Accessible technology skills gap report.* Available from https://www.peatworks.org/skillsgap/report

Reiner, M. (2008). Seeing through touch: The role of haptic information in visualization. In J. K. Gilbert, M. Reiner, & M. Nakhleh (Eds.), *Visualization: Theory and practice in science education* (pp. 73-84).Springer.

Rossi, S., Benaglia, M., Brenna, D., Porta, R., & Orlandi, M. (2015). Three dimensional (3D) printing: A straightforward, user-friendly protocol to convert virtual chemical models to real-life objects. *Journal of Chemical Education, 92*(8), 1398-1401. https://doi.org/10.1021/acs.jchemed.5b00168

Rowland, M. P., & Bell, E. C. (2012). Measuring the attitudes of sighted college students toward blindness. *The Journal of Blindness Innovation and Research, 2*(2), 1. http://dx.doi.org/10.5241/2F2-24

Scalfani, V., & Sahib, J. (2013). A model for managing 3D printing services in academic libraries. *Issues in Science and Technology Librarianship, 72*, https://doi.org/10.5062/F4XS5SB9

Shimizu, Y., Saida, S., & Shimura, H. (1993). Tactile pattern recognition by graphic display: Importance of 3-D information for haptic perception of familiar objects. *Perception & Psychophysics, 53*(1), 43-48. https://doi.org/10.3758/BF03211714

Shinohara, K., Kawas, S., Ko, A. J., & Ladner, R. E. (2018). Who teaches accessibility? A survey of U.S. computing faculty. *Proceedings of the 49th ACM Technical Symposium on Computer Science Education, 197-202.* http://dx.doi.org/10.1145/3159450.3159484

Smith, D. W., & Smothers, S., M. (2012). The role and characteristics of tactile graphics in secondary mathematics and science textbooks in Braille. *Journal of Visual impairment & Blindness, 106*(9), 543-554. https://doi.org/10.1177/0145482X1210600905

Spiel, K., Gerling, K., Bennett, C. L., Brule, E., Williams, R. M., Rode, J., & Mankoff, J. (2020). Nothing about us without us: Investigating the role of critical disability studies in HCI. *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*, 1-8. https://doi.org/10.1145/3334480.3375150

Stone, B. W., Kay, D., Reynolds, A., & Brown, D. (2020). 3D printing and service learning: Accessible open educational resources for students with visual impairment. *International Journal of Teaching and Learning in Higher Education, 32*(2), 336-346.

Stone, B. W., & Brown, D. (2021). Changing attitudes about visual impairment in the college classroom. *Journal of Blindness Innovation and Research, 11*(1). https://doi.org/10.5241/11-200

Syed, I., Bishop, M., Brannon, S., Hudson, E., & Lee, K. (2022). Designing accessible elections: Recommendations from disability voting rights advocates. *Election Law Journal*, *21*(1), 60-83. https://doi.org/10.1089/elj.2020.0677

Teach Access (2018). Teach access institutions course list (coded) [Data set], Available from https://docs.google.com/spreadsheets/d/1YGAQEuAOB-4Tv2gFf6gfPNJfzcgwiRt1X_eOhiR2rDHY/edit#gid=1516581604

The Center for Universal Design. (2008). About UD. The Center for Universal Design. https://projects.ncsu.edu/ncsu/design/cud/about_ud/about_ud.htm

Wijntjes, M. W. A., Lienen, T., van Verstijnen, I. M., & Kappers, A. M. L. (2008). Look what I've felt: Unidentified haptic line drawings are identified after sketching. *Acta Psychologica*, *128*, 255-263. https://doi.org/10.1016/j.actpsy.2008.01.006

Wiley, D., Blizz, T. J., & McEwan, M. (2013). Open educational resources: A review of the literature. In J. Spector, M. Merrill, J. Elen, M. Bishop (Eds.), *Handbook of Research on Educational Communications and Technology* (pp. 781-789). Springer. https://doi.org/10.1007/978-1-4614-3185-5_63

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