# Challenges to Inclusive and Accessible Prototyping, Isotyping and Production


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# Vision Statement

The embodiment of technological customization and innovation in the physical world is an encompassing need that is shared by makers, designers, students, engineers, and everyday people with disabilities. This future should be enabled in an inclusive way that allows people with a wide variety of abilities to make: from DIY makers and medical providers to K-12 students, and those from different socio-economic backgrounds. To do this it also needs to include teachers, medical providers (Lakshmi et al, 2019) and caregivers, and generally include people with and without disabilities and supporting organizations, all with a wide variety of expertise bases. We envision such making, in the most robust and supportive sense, involving a network of stakeholders and allies over the lifetime of the made objects.

An inclusive take on this vision would address a range of accessibility needs (e.g. Hamidi et al, 2015; 2019; Noman, 2017; Chen 2016). This means building interactive devices and systems that can sense and respond to the real world (Hodges, 2020).

Thus, by its nature, making draws from a wide range of expertise including design, mechanical engineering, electrical engineering, hardware, and rehabilitation medicine. In addition, *who makes* must include people with disabilities in the accessibility space, as there is a vast graveyard of well-intentioned accessible technologies designed without guidance of those who will use the technologies that we will otherwise be more likely to add to than not. Making and STEM fields have historically, and problematically, excluded people with disabilities. This must be rectified.

An important consideration in making is that social systems, as much as or more than tools, are essential to its success. For example, peer-to-peer and cross-stakeholder collaboration; support for debugging and repair over the lifetime of the made artifact; support for needs assessment; and teaching and learning are all essential components of successful, inclusive making.

Rather than specifying what might be made, which has infinite possibility, we specify characteristics of importance for the tools, support mechanisms and stakeholders involved. From an application space perspective, this leads us to think about things like *medical, decorative, expressive and functional devices*. Of course, these may all overlap, and there are tradeoffs between them. For example, in some cases form is more important than function (Profita 2016), as when deaf people use hearing aids to make their deafness visible, rather than for functional reasons (Profita, 2018). Considering further device characteristics, devices may include *software,* versus designing *static physical shapes*, adding *mechanical actuation,* and adding *digital interaction.* Any physical embodiment may also need to consider fit and attachment to function in a real-world context (to existing, physical real-world objects and spaces). All these again may overlap, and further we might think about "piggybacking" on an existing device, either by adding physical components to it (such as the Interactiles overlay for mobile phones, Zhang et al, 2018) or by adding software to existing physical devices.

# Next Steps for Inclusive Prototyping and Production

What *store of tools* might be implied by this array of individuals and goals for making? The space is of course incredibly broad. Making is extremely broad, and the innovations that are needed are equally broad. However, we can identify some important categories of innovation. At the core of our proposals is the idea that making should take place in an ecosystem – that once something is made, it should be possible to re-use it, build on it, modify it, repair it, and that the group of people that might want to do this will vary as broadly as do those who compute today, and share a wide variety of relationships with disability.

Our conversation uncovered four important lifecycles in this context:

- **Artifact Lifecycle:** First, the lifecycle of the artifact itself, which follows a standard iterative design process, not all that different from programming, including variations on needs finding, design, development, testing, deployment, and follow-up (including revision, repair, and replacement). Concerns here include fit, safety, function, and stakeholder representation within the process (Von Hippel, 1976).

- **Manufacturing and Distribution Lifecycle:** Second is a manufacturing lifecycle. Here, we might think of a process that goes from paratyping (Hayes 2013) to prototyping (Wensveen 2015) to isotyping to production, with concerns arising around testing, sourcing, reliability and so on.

- **Information Sharing Lifecycle:** Next, there is the information sharing lifecycle. This overlaps the prior two, but also diverges from them. Here, we go from design to generalization to publication, with concerns arising around documentation, parameterization, interfacing, reliability, safety, among others

- **Maker Lifecycle:** Another important lifecycle is that of the maker themselves. This encompasses growth from awareness and interest in the relevance of making through various kinds of exposure and learning to modifying, customizing and ultimately making new things. As makers engage in such practices in informal and formal learning environments (e.g., structured classrooms, library makerspaces, and vocational or occupational rehabilitation settings) they develop new skills and competencies. As makers' skills and competencies develop, the door is opened to careers in STEM/STEAM or making-informed accessibility work, including potentially things like healthcare work, DIY community, and small business creation. A special concern in this domain is ensuring that do-good work is informed by actual need/experience, and that it comes with appropriate support and follow up over time. A good way to accomplish this is to engage with, encourage and support making among people with disabilities, giving stakeholders agency and control over what is made.

Given these four critical areas that intersect with making, we note that there is critical need for accessible tools and instructional materials and feedback mechanisms at every stage of these lifecycles. Further, these tools and materials need to support a variety of expertise, including empowering domain experts at the level that end-user-programming tools today empower a range of people to program. Across all of these, it is critical that we identify barriers specific to people with disabilities and address them so that we can level the playing field of who can work with hardware and fabrication. We provide a few examples of each below and pose a number of questions and thoughts:

## Artifact Lifecycle

How do we make inclusive tools that do not sacrifice individual ability-based affordances? Previous works involving need-finding processes often found very individual needs. Can we pursue universal design without sacrificing specific needs? Accommodations built on false assumptions can feel very constraining if it is not the preferred accommodation (everywhere from ATM to high stakes testing) because it supersedes what the person normally would use. A user-centered design process should forefront questions of agency and control, question whether structural issues need to be addressed first, and encourage designs that don't override existing functional accommodations.

This goal also has implications for the tools we create. Can we create artifacts that can sense and adapt to the physical world similarly to ability-based design in software (Wobbrock 2018)? How do we make up for the gap between ability assumptions and what people bring to the device? For example, there are great examples of operating a trackpad with a chin; typing with toes - but the device has no idea this is happening, and thus may make things more awkward or error prone than necessary.

Other questions we should ask about our tools include:

- What expertise/ability is required or assumed by the tools we create?
- How do we support assembly?
- How about debugging?
- Customization or personalization?
- Testing? Reliability? Maintenance?
- Are we ensuring that all of these processes are accessible to people with disabilities, especially those using a particular artifact?
- How do we stage tools to be accessible across the spectrum from super easy to complex while remaining accessible?

To this end, we call for the equivalent of accessible end-user-programming for physical computing (including support for specifying *what* fits the environment of use (size, attachment, functional goals, etc), using libraries and APIs that expand what you can build; easily understood and multimodal representations; and debugging support). Such a tool should also support the artifact design lifecycle in the context of ecosystems of makers such that maintenance, customization, repair, and adaptation over time are supported, as well as domain-specific needs such as reduced iteration [Hofmann et. al. 2019].

## Manufacturing and Distribution Lifecycle

Questions to consider in this context include:

- How do we create multiple copies of prototypes – something we call *isotypes* – that replicate something at various scales?
- How do we ensure something is robust?
- How about when we replicate it at scale?
- How do we adjust a design based on the distribution channels available? For example, if the availability of a button changes, can we adjust for firmware, software, and physical housing easily and effectively?

## Information Sharing Lifecycle

As individuals create unique and valuable solutions, how can their results be effectively shared with a wider community? If others are expected to make a design for themselves, how do we ensure designs and the process for making them is accessible by default? Where is documentation kept and how can we make it an embedded and accessible part of any design? How can tools improve on our ability to do this properly? How do we build on the past – modifying and or combining prior solutions – effectively?

How do we support specific requirements such as producing things at a certain speed when urgent (something that came up with access to graphics about critical health information, for the blind, during COVID)? Further, how can we build systems and tools that ensure that even under pressure, disabled voices are not excluded.

What does it mean to design something that is parameterized – as what is the equivalent in hardware; flexibility; modularization – can you swap things out? How can you personalize and when (at manufacture time or at use time for example?) How do you personalize something and when is appropriate to do so? Also discussed IOT accessibility as a space where people with disabilities are both innovating and running into barriers now.

To the extent that shared artifacts also are tools for learning, the need to make these designs themselves accessible is critical, and ties into the creation of meta-design for learning \point made earlier.

## Maker Lifecycle

How do we create product delivery systems that position educators, who often have little preparation time to learn how to use new technologies, with expertise to facilitate projects (towards a specific learning goal, e.g., CS skillset, product design for business development, etc.)? How do we match hardware activities with specific learning standards/expanded core standards? We must prepare teachers; align accessible making education with the priorities of K-12 educators and students and connect this to STEM learning in general. Further, we must make this accessible to students with disabilities, not only in K-12 but also expand this into the domain of rehabilitation programs; college students; and PhD students and professionals with disabilities. Tied to this is the need to create equitable student outcomes and employment opportunities.

In education some students get fantastic experience with easy and inspirational products and others have access to only broken scraps or nothing at all. How do we create guidelines or resources for under resourced schools and hard-to-reach communities that are thinly and widely spread? Can we develop curricula that depend on a small number of devices, such as a single 3d printer that could serve a whole school? Can we extend this to prototyping hardware? What are the implications for motivation of people spending months on crafting a digital item and then at the end having to pull the item apart to reuse the component because they are too expensive to leave in the item that has been built? We argue that developing low-cost tools such as micro:bits (Austin et al., 2020) is an important need for this problem space. However, it is not sufficient. We must also ensure that the design of K-12 and higher education materials and laboratories support access by students with disabilities. This is particularly difficult because of the dependence on graphical information in informal and formal collaboration, as well as in powerful and important tools like Solidworks.

Further, we must create meta-design tools and approaches that encourage expert makers to develop accessible hardware that is easily recognizable and usable by disabled students. We should further make it easy for hardware developers, manufacturers, and makers to follow templates, so they don't have to rediscover best practices for accessibility. We also need to make materials to make hardware such as the Arduino accessible (e.g., recognize anatomy of hardware). Furthermore, this also includes templates for activities. For example, how would someone who's blind think about designing templates for hardware design/accessibility features?

Finally, in the spirit of eating our own sauce, we must ask how making by people with disabilities is being done today. Our approach should be informed by the problems and goals that arise in this group (e.g., see Stangl 2019, Buccafusco, 2020 and Jackson, 2018).

How do we create a platform for allies (friends, family members, rehab professionals, focus population, etc.) to build custom digital input set ups for those they care for and collaborate with? How do we enable this flexibility without compromising cost?

How do we enable someone with a disability, to not just make something, but create an effective career out making that thing? What support structures, community, expertise can empower them to do so? The answer to this question should extend from the education level that allows them to make the thing, to giving it to others and continuing that cycle, isotyping; sourcing; (manufacturing lifecycle vs product lifecycles).

It is unlikely that we can solve these problems without engaging with specific subcommunities of the disability community. For example, how do we give a seat at the table to people who have communication difficulties? How do we support and teach 3D modeling for nonvisual students, as well as for collaboration between nonvisual and visual students?

# Needs for Successful Progress

While the actions laid out above are a starting place for action, it also helps to consider the near-term practical needs for progress on this agenda. First we lay out a framing set of questions that we think should drive any progress forward.

## Agenda and Results

What does it mean to approach education from a space/assumption of expertise – as ensuring that people with disabilities can learn fabrication and making alongside their peers? This is an understudied space in ASSETS and academia, as well as in K-12.

Structure this to create tangible benefits, first, and make research optional if people want to also be interviewed etc. This makes sure everyone in the transaction is benefiting and creates meaningful involvement in disability culture and spaces. Further, from the perspective of a participant, the transaction should ensure that the participant is contributing and not the "experiment". Ultimately, this may not look like traditional research but end up having publishability in addition to their other benefits.

Lastly, we must create tools that support disability justice and values in making. This means:

- Providing a user control over how they work and how/when to use the object they are making.
- The tools must be designed in a manner that the thing being created is reliable and robust.
- Can be shared and reproduced.
- Can be made *and modified* by domain experts.
- Support learning as well as products.

Ultimately, we *must* increase agency and control for and by people with disabilities.

## Data Needs

While this work is not focused specifically on intelligent systems, today's most advanced programming and CAD tools almost all leverage AI, and underlying that data, to improve the experience of end users, and such approaches would likely also be of great value in making such tools accessible. Data regarding the products, data production processes, and user/maker behavior or practice would all be of value. Here we provide some examples of data we would like to see collected and to leverage in our work. Further, while this data can help support research and system development, it also represents an open-source future for accessible technologies themselves – we should share high quality designs for people to make their own, along with the educational supports necessary to help with this.

- Artifact data about things are being built. This includes 3D models of accessibility technology, knitting patterns; and circuit instructions.

- Manufacturing and distribution related data, such as data about how many 3d models are turned into 3d prints; or how much people spend at Shapeways etc. vs. how many people print themselves.
- Data about users such as Fusion360 modeling histories (e.g. Willis, 2020) or data about failure points, or how beginning versus expert modelers iterate. This also requires asking the question of how we collect such data equitably and representatively.
- In the past we used to measure the success of software based on how many copies were sold. But these days with software being purchased by the use, or by the month, sometimes people use 'monthly active users' as a metric. These same metrics could be useful in assessing physical computing use.

## Expertise needs

We argue that this agenda is best met by a range of practice and research experience. Our workshop group had great representation from both. For example, Chancey Fleet's work focuses on empowering Blind and disabled learners to achieve their technology goals by working with confident assistive technology users within the public library system. Her current initiatives include workshops on physical computing with the Blind Arduino Project, 3D design with OpenScad, and the NYPL Dimensions Lab for learning about and creating accessible tactile graphics and 3D models. At another end of the spectrum is Megan Hofmann, who combines stakeholder engagement with medical makers and tool building for fabrication focused primarily on the artifact and information sharing lifecycles. Teddy Seyed gives an example of how tool building can inform the education space by making prototyping more accessible and providing agency and control in those experiences. Accessible K-12 education and making is the focus of Xing-Dong Yang's work. There is a deep need here, for example Josh Davis' thesis has found that only 2% of online web tutorials are accessible (Davis 2020). This motivates the creation of communities of practice to support accessible and inclusive design practices and learning materials by Abigale Stangl (Stangl et al., 2019), and STEM engagement activities by Kirsten Ellis and Sam Reinders (e.g. see Reinders, 2020). Other expertise among the authors includes work on the manufacturing lifecycle by Steve Hodges (Hodges and Chen, 2019; Khurana and Hodges, 2020); physical computing systems research and development by Steve Hodges and James Devine (Devine et al., 2019; Austin et al. 2020); improvements in CAD accessibility for the blind by Sean Follmer; improving knitting accessibility by Taylor Gotfrid, and Jacob Wobbrock's work on input and interaction techniques and ability-based design (Wobbrock, 2018).

## Collaboration Needs

Connected with expertise is the importance of representation and inclusion in the work we do. While the research being done by our group already has representation of people with disabilities, it is important to ensure that we include more perspectives than PhD-level researchers. Further, this must be done in an ethically considerate way.

The ethics of working with communities of people with disabilities are complex. Some areas of concern include the following.

- Disparity: people on disability pensions with payment not great working with technologists who are in the top percentage of payment … contribution is just as valuable but not getting paid for it.
- Participants with disabilities being over asked to contribute without their expertise being rewarded both in terms of financial reward and recognition in being named on papers.
- The concept of informed consent for people that have a cognitive disability.
- Who should give consent for adults that may not know what they are consenting to?
- Language can be regarded as community owned – and if so, who should profit from it? The designers, the community or the users? For example, sign language instruction or recognition/translation.
- Are we compensating partners and participants appropriately for their time? Financially, this is further complicated by the fact that people on disability pensions may not be able to accept payment. In addition, other types of compensation such as co-authorship should be considered.
- Additionally, we must consider the ethical obligations for researchers developing custom solutions when it comes to supporting those solutions in an ongoing fashion? On the one hand, if we don't invent and explore new solutions, we fail to make progress. On the other hand, if we create useful solutions but can't deploy or support them (particularly hard from academia), then we're just letting them collect dust on the shelf, and "using" participants for our next publication.

Who is included has implications (potentially) for the workforce, safety, regulation, etc. and is impacted by policy, assumptions, and community values (among other aspects). In many ways this is specific to a given project, the degree to which certain stakeholders are wanted and/or problems arise in trying to include them.

Further, inclusion does not just mean people with disabilities. For example, many accessibility projects fail to consult with medical providers even when that might be an appropriate consideration from a safety or therapeutic perspective. Other allies such as family members and educators are also important to include – in fact, it is valuable to take an ecosystem approach both to see hidden structural barriers and to develop viable solutions.

It may also be important to include practitioners, such as production specialists who can support scalability (prototype to the isotype, and beyond); or technical expertise in each of the different aspects of design and fabrication; domain experts; or people to facilitate field testing with large segments of the populations, who can deliver actionable data about users' engagement with the product (with focus on responses to ability-based design features); policy makers; and people with understanding of compliance issues / educational requirements

# Reflecting on Next Steps

Throughout this white paper, we have described several different challenges in the areas of accessible prototyping, isotyping and production. What became apparent to all authors is that there is much that can be collaborated on with ourselves and the wider community, both to create novel solutions and to also reduce duplicated work. Consequently, some our next steps are as follows:

- Identify co-operative research areas and opportunities.
- Provide and support these opportunities for students, researchers and others with disabilities.
- Organize a working group around this topic, with an invitation to the wider community in the coming year.

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