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One Size Doesn't Fit All: On the Adaptable Universal Design of Assistive Technologies

L. Aflatoony [1,✉] and S. Kolarić [2]

[1] Georgia Institute of Technology, United States of America, [2] Simon Fraser University, Canada
✉ leila.aflatoony@gatech.edu

Abstract

Occupational therapists modify mass-produced and universally-designed assistive technologies (ATs) to fulfill the specific needs of people with disabilities. We interviewed ten occupational therapists with experience in modifying ATs in order to understand adaptation processes. Our findings reveal the reasoning behind adaptation, common ATs that require adaptation, as well as the collaborative nature of adaptation. We propose a new framework called Adaptable Universal Design (AUD) that blends Universal Design with the need to adapt ATs in order to fulfill unique and specific user needs.

Keywords: inclusive design, healthcare design, design theory, design guidelines

1. Introduction

An assistive technology (AT) is any item, piece of equipment, software, or product system that is used to increase, maintain, or improve the functional capabilities of people living with impairments and disabilities (PwIDs). ATs are categorized according to the complexity level of the technology used, materials, and operations. They are often either acquired commercially off-the-shelf or customized to fit the specific needs of individuals with disabilities (Smith et al., 2018). Off-the-shelf devices are often mass-produced and developed according to the principles of Universal Design to support individuals with a broader spectrum of abilities (e.g., keyboards, switches, and computers). Customized ATs, on the other hand, follow Accessible Design principles to support PwIDs with unique abilities/needs (e.g., feeding devices, manual wheelchairs, and hearing aids). The purpose of both approaches is concerned with addressing the needs of PwIDs beyond those considered to be average/standard users within the spectrum of human abilities.

Despite the significant efforts to develop universal ATs that are accessible and can be purchased off the shelf, ATs that support certain types of disability can be irrelevant to others. Therefore, there is an ongoing need for *ATs adaptation* and the iterative process of modifying so-called universal designed ATs to support/fit individuals' unique needs/abilities. It is common for AT specialists (e.g., occupational therapists) to find the need for modifying off-the-shelf ATs after they fail to support PwIDs' needs, abilities, and specific activities (Aflatoony and Shenai, 2021). The adaptation process necessitates tweaking, shifting, and repurposing existing ATs using Do-it-yourself (DIY) approaches and everyday materials such as Velcro, thermoplastic sheets, and foam tubing (Aflatoony and Lee, 2020b; Hofmann et al., 2019). Other methods to AT adaptation include using rapid prototyping to create more durable and custom-designed components (Buehler et al., 2015; Hofmann et al., 2016). AT experts' practices overlap with the maker culture (Buehler et al., 2014; Hurst and Tobias, 2011; Parry-Hill et al., 2017). However, AT adaptation processes follow a more rigorous clinical process that requires assessing the liability of outcomes against PwIDs' abilities, physical/cognitive limitations, and complex psychological/social needs. Any potential complications in the artifact can

negatively impact patients' health, safety and may cause serious injuries (Hofmann et al., 2019). This study investigates the shortcomings of off-the-shelf ATs that still require adaptation by Occupational therapists (OTs) to meet PwIDs' specific needs. We interviewed ten experienced OTs to understand better off-the-shelf ATs' shortcomings associated with necessary adaptations and types of ATs that require frequent modifications. We discuss the results explicitly within the broadly used frameworks of Universal Design, Accessible Design, and Specialized Design. We propose a new approach, termed *Adaptive Universal Design (AUD)*, to support off-the-shelf ATs modifications continuously and iteratively.

2. Background

2.1. Assistive Technology Design and Adaptation

Despite the benefits of AT in improving the everyday functioning of individuals with disabilities, disuse and abandonment of off-the-shelf ATs has long been a problem due to either a failure to adequately meet users' needs or the lack of fit between AT and end-user abilities (Gitlin et al., 1996; Phillips and Zhao, 1993). To overcome these problems, occupational therapists (OTs) and other AT specialists, as prescribers of AT, often need to modify, refine, or repurpose existing off-the-shelf AT to better meet their clients' specific needs and (Dixon, 2019; Hofmann et al., 2016; McDonald et al., 2016). While OTs' clinical knowledge contributes positively to AT adaptations (Aflatoony and Lee, 2020a; McDonald et al., 2016), these practices typically involve hacking and makeshift methods, often using improvised materials at hand (Aflatoony and Lee, 2020b).

Despite OTs' initial goal to find off-the-shelf ATs through available resources, making adaptations is often necessary and unavoidable. The step-by-step process of AT adaptation by OTs requires integrating clinical reasoning/assessment into the decision-making processes. Adaptation often follows a step-by-step process of clinical evaluation, building rapport with patients, purchasing off-the-shelf ATs, defining the need, adaptation, having access to resources, and post adaptation/validation (Aflatoony and Shenai, 2021). OTs use commonly found materials (e.g., tape) or standard tools (e.g., scissors) and occasionally use specialized materials (e.g., heat shrink tubing) and devices (e.g., soldering iron) for more advanced and complex modifications (Aflatoony and Shenai, 2021). Efforts have been made to incorporate digital fabrication and rapid prototyping to facilitate AT design/adaptation in OTs practices. Nevertheless, the complexity of using CAD interfaces and having access to 3D printing tools are just a few shortcomings (McDonald et al., 2016). In addition, these technologies are not consistent with the current OTs practices, particularly modifying, adjusting, and repurposing the universally designed ATs.

2.2. Disability-Specific Design Approaches

A variety of approaches to designing ATs have been adopted in the past.The most common ones include specialized design, accessible design (accessibility), universal design (design for all), and inclusive design. These approaches provided an opportunity to consider PwIDs and their needs in developing technological and non-technological products/systems. More specifically, specialized design is a person-centric approach and is meant to support PwIDs with unique needs, abilities, and activity barriers (Yang and Sanford, 2012). Specialized designed ATs often follow adaptations processes according to specific types of abilities, so they are not compatible with other users' needs at large; Nevertheless, person-centred approaches are valuable in developing unique environments/products that support independent living and activities of PwIDs (Kerssens et al., 2015). Specialized design is particularly common in the field of rehabilitation and occupational therapy to provide individualized support through ATs and in developing personalized design technologies (Lin et al., 2014).

On the other hand, the overarching goal of universal design, inclusive design, and accessible design approaches is largely focused on increasing the accessibility of environments, tools, and interactive systems for the widest possible range of users with and without disabilities (Persson et al., 2015). More specifically, the universal design included seven principles and was defined by The Center for Universal

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Design at North Carolina State University as "*The design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design*" (Connell et al., 1997). Universal design is rooted in barrier-free and accessible design approaches and recently has been referred to as design for all (Persson et al., 2015). The universal design can be idealistic and challenging to incorporate due to its complexity; nevertheless, it allows better product accessibility and usability for people within a wide range and spectrum of abilities. Examples of universal design products include doors that automatically open when a person moves near them or a multimodal application to support different levels/types of interactions and modes of input-output.

Accessible design specifically considered the needs of PwIDs. ISO's guide 71 described it as "*design focused on principles of extending the standard design to persons with some type of performance limitation to maximize the number of potential customers who can readily use a product, building or service [that] is usable by most users without any modification*" (ISO/IEC, 2001). While accessible design is legally mandated (i.e., designs must be in compliance with its mandates), universal design is not and is instead driven by commercial and competitive concerns (Erlandson, 2007). For example, the Americans with Disabilities Act (ADA) mandated that public facilities are fully accessible to PwIDs or the Web Accessibility Initiative provided guidelines for designing accessible web pages.

Inclusive design definition overlaps with universal design but emphasizes the notion of mainstream products, which eliminate the need for ATs in the definition: "*The design of mainstream products and/or services that are accessible to, and usable by, as many people as reasonably possible on a global basis, in a wide variety of situations and to the greatest extent possible without the need for special adaptation or specialized design*" (Normie, 2005). The phrase "reasonably possible" illustrated the main difference with other approaches as it considers the inclusion of PwIDs when possible (Persson et al., 2015). Shipley (2004) defined the approach as follows: "*inclusive design is not a fixed set of design criteria, but a constantly evolving philosophy. The goal of creating beautiful and functional environments that can be used equally by everyone, irrespective of age, gender, or disability, requires that the design process must be constantly expanding to accommodate a diverse range of users, as we develop a greater understanding of their requirements, desires, and expectations*."

3. Methodology

3.1. Participants

For this study, we recruited ten OT professionals with formal OT clinical training and extensive experience in AT modification and AT prescription to their clients. The inclusion criteria for recruiting OTs was their previous experience with creating/adapting ATs. All participants have been involved in OT practice for 5 to 45 years (Table 1). Three participants are currently university professors (and practitioners) in occupational therapy, while the other seven OTs are clinicians (OT registered/licensed [OTR/L]) working in private/public health care organizations. We recruited participants by posting flyers in American Occupational Therapy Association (AOTA) and used snowball sampling techniques to target local participants.

Table 1. Demographics of OT participants involved in the semi-structured interviews.

Participant	Gender	Current organization	Years as OT
P1	F	OTR/L - Select Physical Therapy	27
P2	M	OTR/L - C Berstecher Consulting	27
P3	F	OTR/L - Elderwood Health Care	16
P4	F	OTR/L - EDC Home Modifications	30
P5	F	Clinic director - Therapy Works	23
P6	F	OT professor - San José State University	45
P7	F	OTR/L & PhD student - Georgia State University	5
P8	F	OT professor - Brenau University	11
P9	M	OT professor – University of Missouri	9
P10	F	OTR/L - Kindred at Home	25

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3.2. Semi-Structured Interviews

We conducted semi-structured interviews with ten expert OTs to explore off-the-shelf ATs' shortcomings, reasons behind the ATs adaptation, and types of ATs that frequently require modification. We asked questions such as:

- How do you decide/define whether an off-the-shelf AT needs adaptation?
- What factors do the adaptations depend upon?
- What types of AT adaptation are most common in OT practices?

Each interview session took between 50 and 75 minutes with an average time of 60 minutes. We audio-recorded the interview sessions and asked participants to sign consent forms before each session. After completing the interviews, we started the data analysis by transcribing the files into plain text. We anonymized participants' names (P1–P10) to protect their identities. We then used the affinity diagram technique, an inductive process suggested by (Holtzblatt and Beyer, 2017), to analyze the user data for recurring patterns/themes. We examined the emerging themes iteratively by sorting and resorting the data into categories and subcategories.

4. Reasons Behind Adaptation

The interview results revealed several reasons behind ATs adaptations, mainly due to body conditions of PwIDs, shortcomings, and costs associated with off-the-shelf ATs. OTs consistently stated their primary goal being prescribing ATs off-the-shelf and avoiding product modification as much as possible. However, they shared multi-faceted challenges of patients often requiring ATs modification. Such a process is often time-consuming, dependent upon having access to material resources and OTs' abilities to make the necessary modifications. In the following sections, we summarize the reason behind adaptation as specified by OTs.

4.1. Uniqueness of Body Functions/Conditions

OTs brought up the uniqueness of their patients' body conditions as one of the reasons behind AT adaptation. For example, P2 described: "*So they get the Reacher and now that extends their reach. But maybe they have cerebral palsy, so they have a lot of specificity in their fingers or hands. So we might need to modify the switch of the trigger that squeezes to reach or handle clamps*." Likewise, P4 brought up an example of a patient with a specific body condition and stated: "*It has to do with a deformity, or perhaps let's call it like spasticity. So maybe they have severely limited motion, so they can't wrap their fingers around something, or they can wrap two fingers but not their whole palm. So I need to build it up so that they can get a partial grip on it.*" Some OTs expect to do modifications even before purchasing and exploring ATs off the market. P4 described assessing the body conditions of patients in advance and deciding if adaptation is required: "*Maybe because of spasticity or congenital disabilities [...] is that person's physical body far away from the standard? Then, I have to buy something and then modify it to get it to work for them.*" P1 brought up an example and explained, "*If they have bilateral elbow fractures and their immobilized bilateral elbow, they can't bring their hands to their mouth. you know a lot of my employers will not buy specially extended silverware, so as an OT, I have to grab the splint material and actually make it.*" The decision behind AT modification is associated with the severity level of physical disability, as described by P6: "*For people who have high spinal cord injuries, how are they going to be able to play games or use the computers or drive their wheelchair? What kind of adaptations might be needed*?"

Due to specific body conditions of patients, AT devices for activities of daily living (ADLs) often require modification. For example, P4 reported: "*There are all sorts of products on the market for built-up spoon handles. Things that you can put on the end of a brush, but maybe someone has a deformity. That they might need a very customized grip, or they might have very limited strength. So, I might want to customize a grip where they're using their shoulder more than their wrist*." P7 shared a different example and described: "*That spoon with a bent towards the right is really not going to do anything for a person who needs to use their left hand. [...] can I adapt it? can I reshape that spoon in some way to make it more useful for that person?*" Similarly, P3 stated: "*Thinking of somebody that*

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would need a special spoon. You know, one person might need it out of a 45-degree angle, or somebody else might need it at a 70-degree angle."

4.2. Changes in Bodily Functions/Conditions

OTs shared the need for AT adaptation for individuals with health conditions and progressive diseases that cause changes to their physicals. These alterations often contribute to their activity limitations and change in their needs. P1 described that ATs should be designed to be adjustable because, "*If someone has hand swelling and they put a special fork holder on their hand and then the next day their hand is less swollen because their lymphoedema is being managed… and now there, whatever you have on their hand is too loose or too big*." P9 shared another example and stated, "*I'm working primarily with people that have ALS. The most common issue is a decrease in upper extremity function. And so it's trying to overcome whatever the new deficit is and planning for future deficits. Because we're talking about a progressive, neurodegenerative condition*."

Due to the change of body conditions, P9 explained that modification would be effective for a short-term use: "*Since we only see people once every three months, if I make an adjustment to a device three months later, or six months later, that adjustment might not have done any good*." He elaborated on his statement and further described: "*We may have provided AT, but then they come back to a subsequent visit, and we ask, are you still using this device and the answer? There are more often than not as either no or yes, but I had to make some adjustments to it and change how I use it, or it doesn't quite meet my needs, so I use it sometimes*." The change of body condition and lack of fit with ATs are common challenges among older/younger populations as described by P2: "*If you're dealing with aging people because what they can do now, maybe they can't do five years from now, and you're back to redesign. Or if they have progressive diseases or disorders [such as] Parkinson's or muscular dystrophies, they present challenges because their abilities change*." Similarly, P6 stated: "*I used to work with children with limb deficiencies, and you know they grow so quickly and it's expensive to provide the different prostheses.*"

4.3. Functional Limitations of Off-the-Shelf ATs

Several OTs shared their concerns about the limitations of off-the-shelf ATs and the continued need for adaptations. P2 described: "*I've been doing a lot of feeding and have found a lot of products off-the-shelf. They kind of work, but there's always something about it that doesn't really work out [...] it's more common than not that [those] things don't exactly work right. You're trying to put a square peg in a round hole*." Likewise, P3 and P4 mentioned if "*you buy it off the shelf, it is never great, it's never perfect!*" and "*there is always a need for adaptation!*" P2 also described: "*forty years ago, we had engineers [...], taking apart telephones and rebuilding them, and now, most assistive technology is off-the-shelf. However, one size doesn't fit all!*" P6 brought up a high-tech example and described: "*it might be some technology that needs two hands to use, and the person may only have one hand that they can use, or they may have coordination [problem] or ataxia. So, they need something that's not as sensitive in terms of a response. They need to be able to control that.*" Due to these shortcomings, P1 stated that "*a lot of hand therapists don't even like the prefabricated splints. They want to make it from their own pattern and their own format.*"

Additionally, using ATs may affect patients' other abilities/health conditions negatively. For example, P2 stated: "*often, you'll see a person with quadriplegia, use a mouth stick [...] if you keep a bite stick in your jaw all day long, or a lot of time in the day, you can actually develop a TMJ Disorder. You know, then you start clicking, and he has pain in the jaw.*" He brought up another example and described: "*what I'm mainly using these days is the battery-operated toothbrush. On the one hand, they keep [patient] from having to do a lot of up and down movements with the arm and the hand. You just stick your hand up to it and let the battery do that. But they're a little heavier [than a regular toothbrush], aren't they? So, suppose you have a muscle weakness disability like MS or muscular dystrophy. In that case, we have to make sure that the assistive devices that we are recommending don't wear you out before we even get ready for the day*." To overcome these barriers, P1 suggested: "*the size has to be adaptable cause anything you buy off the shelf is not going to be perfect for*

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everybody […]. If I buy a fork handle, can I adjust it by moving it or melting it?" Similarly, P5 shared his ideal AT example as follows: "*a one size wheelchair that you can adjust and adapt.*"

4.4. Economic Limitations of Off-the-Shelf ATs

Several OTs shared the high costs of off-the-shelf ATs as an essential factor behind adaptations. P2 brought up an example and stated: "*it's very expensive to buy things on Amazon, and then they ship in, and they don't work. Now you gotta send them back, or you can't return them, and now you're stuck with an 80-dollar feeding kit that you can't use. And you have an unsuccessful experience for a person who is already struggling.*" He further explained: "*you don't want to have somebody struggling to earn a paycheck or struggling to pay a water bill [...] introduce an assistive device or devices that are expensive to replace. Maybe they require a lot of batteries over the course of a year, and now you're putting a financial burden on them*."

Similarly, P4 brought up cost as the main factor for adaptation: "*number one is cost and who's paying for it? You know it's the client paying for it because most people with disabilities are on SSI Disability, and they don't have any real income. Is the client paying for it? And suppose the client's paying for it. In that case, I look at quality for the price.*" P10 shared that despite the benefit, some clients may not afford to purchase an AT: "*this $20 piece of equipment is going to make your life a whole lot easier. [Still] some of them may not have the financial ability to pay for it. That is why I like the foam because that's a cheap alternative. And if it doesn't work, you just take it off, take it, take it back off the utensil*." Also, P4 mentioned the lack of durability/product warranty as another issue in off-the-shelf ATs: "*I liked the new and cool things on the market, and I would try to bring them into our clinic. But my boss was like, look! I think these are cool, but they don't have a warranty, so we don't know how long they last.*" P7 shared lengthy shipping of ATs as an associated factor behind adaptation: "*If the person needs a spoon because they need to eat, right? You know that's why I can't wait around for two weeks to get a spoon. If they live by themselves, and they need to feed themselves like that's kind of crucial. So, I need to see what else we can come up with and make that work within the confines of parameters.*"

5. Common ATs that Require Adaptation

The most common adaptations support ADLs (activities of daily living), including eating/feeding utensils (P3, P7, P9, P10), dressing equipment such as Reacher or long shoehorns (P3, P6, P9), and self-care equipment such as oral hygiene and bathing equipment (P2, P7, P10). P4 described that OTs are "*more focusing on perhaps non-technological interventions, like smaller items that I think people need to use every day*." Most adaptations have been made to support patients' ability to hold items or use items with their hands in this category. P9 mentioned: "*We generally work in small manipulative assistive devices.*" P4 elaborated on this statement and explained: "*Sometimes I modify the grips thing, so that could be to a spoon, a reacher, a hairbrush those type of things…even you know the wheelchair joystick is kind of like a grip.*" P6 brought up another example and described: "*the most recent thing I've done is adapting handles on spatulas so that somebody who can't grip with their fingers could use a spatula*." Additionally, OTs shared that PwIDs' ability to use household devices is crucial (e.g., operating switches). P6 described: "*Being able to pull the plug out; we use so many electronic devices that need charging now, so on Thingiverse, there's a device that's like a ring that fits in between the plug and the socket, and so somebody can put a device in there and pull the plug out if they didn't have their finger muscles to be able to pull the plug out though.*" These adaptations take a few different forms, such as extending handles, adding material to change grip size/material/shape, and creating a holder for items so that people can slip it onto their wrist and position device. P1 similarly stated: "*I mean just enlarging tools is a very common task as people might have arthritis so they can't grip something. Like those foam things that you buy [...] you cut them in three-inch pieces you put them on silverware or a tool.*" Overall, while adaptations can be versatile, each increases easier access to items based on the physical needs and attributes of the person.

Surprisingly enough, OTs mentioned that high-tech ATs require adaptation. It is relatively common to modify items, such as controllers, switches, and keyboards as described by P4, P5, P6, P7, and P9. P4 said: "*I graduated with specialization in assistive technology in 1992 [...] I've been doing assistive*

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technology that long, and the one product that I adapt the most would be the drive control on a wheelchair. Because some people need a better handle or a different way to grab the joystick." Likewise, P4 brought up another example: "*modifying a keyboard with what's called a keyguard. So that helps the people isolate their fingers into a specific key.*" P6 also shared an example of: "*controllers for people with more severe physical disabilities who need to be able to turn switches or who want to use gaming devices.*" As a paediatric OT, P4 described that: "*for some children, you might not want all the keys usable, so you might want only to have a few keys that they can put their finger into and activate, like arrow keys or something like that when they're not trying to type. There's using it in a game, so I modify that*." P7 also brought up similar examples: "*adapting a lot of gaining switches for video games and controllers and working with video game products and computer switches*." Moreover, P5, P6, and P9 mentioned that modifying communication devices is a pretty common task for OTs: "*A common AT adaptation that we use is an augmentative communication device. And that is for our kids that are nonverbal, so they could communicate without having to speak*." Less commonly required adaptations include those items that support leisure activities such as special fishing tools (P10) or oversized commercially available items such as bedside commode and shower chair (P9). Still, P9 stated that adapting devices to support leisure activities is crucial and: "*the type of thing that people do with family, and it's usually part of a long family tradition…So those leisure things get to be really important to the quality of life*."

6. Involving People with Disabilities in AT Adaptation

Several OTs clearly expressed the need to collaborate with PwIDs in adaptation processes to achieve the best possible outcomes. P3 described: "*It is a process of working with them to see how they move and how they have their safety [...] the ability to work with your patients and they would then have a better understanding of what it is that you're trying to make. Then you're not going through and making it and having them decide that they're not going to use it just for something that you really could have just on the spot worked with them.*" Likewise, P1 stated: "*If a good OT involves the patient and their problem solving, it's not like we're doing it to them or for them. They have to come up with a problem that we have to solve. Oh, that's why every occupational therapy evaluation, no matter what setting I work in, is outpatient inpatient. If I have to ask the patient, I'm legally allowed to ask a patient, or do you want to be able to do better or easier? I can't decide that they have to decide it*." Similarly, P5 mentioned: "*Occupational therapy is not me doing to you, it's us problem-solving and figuring out this or this is something that we can remediate*."

P5 described that involving the family of PwIDs is critical as well: "*remember that the patient is not an individual. The patient is part of a family, so it's not just their opinion that matters in this. There are also other opinions that you have to take into consideration.*" Additionally, it is common for OTs to engage PwIDs beyond decision-making processes to help make and modify ATs directly. For example, P6 described: "*If some patients needed, say, cutting boards and they only had one hand to cut things, so we needed an adapted cutting board. We would have them make their own cutting board. We might cut it out for them, but we'd have them hammer the nails and put the sign on for being able to keep the food from sliding off the cutting board*." Finally, involving PwIDs contributes to the adaptation effectiveness, as described by P5: "*you could put so much effort into this, but if you know the patient was not part of the process, and they don't have buy-in, it's a waste*."

7. Adaptable Universal Design (AUD) Framework

During three consecutive weeks, we interviewed ten OT professionals with formal clinical training and extensive experience in prescribing and modifying ATs to understand the shortcomings of off-the-shelf ATs requiring extensive additional (i.e., post-purchase) adaptation to meet PwIDs' needs. We summarize our principal findings in the table below:

Based on these findings, we argue that there is currently a gap in the Universal Design approach for designing products/off-the-shelves ATs targeting individuals with unique needs, foremostly due to the critical need for adaptation. Our study illustrated that despite the emphasis in the idealistic aim of Universal Design, Accessible Design, and Inclusive Design approaches to develop products and/or

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services that are usable by all people "*without the need for modification or specialized design*," still many AT specialists are actively involved in adjusting off-the-shelves ATs to help their clients. Thus, we argue that the Universal Design approach would require embracing product/AT adaptation and considering additional/complementary principles in the framework. Some of these principles can be borrowed from the specialized design approach to support developing products to best support 'specific types of abilities' within the broad spectrum of abilities.

Table 2. Summary of findings

Themes	Examples of Conditions	AT Modification & Actions
1) Reasons Behind Adaptation		
1. Uniqueness of patients' conditions	(1) cerebral palsy & specificity in fingers/hands; (2) spasticity / severely limited motion in hand; (3) bilateral elbow fractures; (4) deformity; (5) inability to use right hand	(1) modify switch on Reacher's trigger; (2) create partial grip (for two fingers only); (3) splint material; (4) built-up spoon handles; (5) reshaping spoon with left bent / certain angle
2. Change in patients' conditions	(1) hand gets less swollen; (2) decrease in upper extremity function due to ALS; (3) children (who grow quickly) with limb deficiencies	(1) adjust the special fork holder; (2) overcome the new deficit and plan for future deficits (AT adaptation every three months); (3) providing different prostheses
3. Functional limitations of off-the-shelf ATs	(1) an AT that needs two hands to use, while a person may only have one useable hand; (2) prefabricated splints for various hand conditions; (3) mouth stick used by a quadriplegic person can lead to TMJ disorder; (4) heavy electric toothbrush used by people with MS or muscular dystrophy; (5) fixed-size ATs / wheelchairs	(1) an AT that is not as sensitive in terms of response and is also controllable by both hands; (2) make ATs from own pattern and format; (3) mouth stick with adaptable size; (4) lighter but still functional electric toothbrush (i.e., trade-off weight vs. functionality); (5) ATs / wheelchairs with adjustable/adaptable sizes
4. Economical limitations of off-the-shelf ATs	(1) inability to purchase an AT, even at nominally low prices; (2) uncertainty about durability of an AT; (3) long shipping times for an AT	(1) use surrogates (e.g., blue foam models as a surrogate for an off-the-shelf AT); (2) ensure that the AT comes with an adequate warranty; (3) modify existing ADLs or product (e.g., spoon)
2) Common ATs that require adaptation		
1. Low-tech adaptations	common AT devices for activities of daily living (ADLs) such as (1) eating; (2) dressing; (3) toothbrushing and bathing; (4) holding items or using items with hands	adapting: (1) eating/feeding utensils; (2) dressing equipment such as reachers and long shoehorns; (3) oral hygiene equipment; (4) building up grips, spoons, reacher, hairbrush, wheelchair joystick, handles, phone holders, blue foam
2. High-tech adaptations	conditions related to operating (1) controllers, switches, keyboards	adapting (1) keyguards, gaining switches, augmentative communication devices
3. Adaptations for leisure & family life	inability to engage in: (1) leisure activities and (2) family activities	adapting (1) special fishing tools; (2) games
3) Involving people with disabilities in AT adaptation		
1. The need for collaboration	(1) diagnosing the problem; (2) creating an AT that suits PwID's needs and achieves buy-in	(1) PwID and OT jointly diagnosing and solving the problem; (2) involve the PwID in co-creating the AT
2. The need to involve PwID's family	(1) considering the wider (familial) sociological context	(1) engage PwID's family members in need discovery and AT co-creation to achieve a better fit

We thus propose a new approach to designing ATs that allows modification, which we tentatively term *'Adaptable Universal Design' (AUD)* framework. This article does not provide a definitive design principle/guideline for incorporating the AUD framework. However, we provide preliminary

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guidelines and the definition and the application area examples that can contribute to the further development of the AUD framework. The framework should support 'extreme adjustability' as a principle that takes into account individuals evolving/unique needs due to the changes to bodily condition/function and allows modification of previously designed products. In other words, products and environments created using AUD principles should not be regarded as '*permanent*' once deployed but can be modified further and grown with individuals. In AUD, every object, artifact, and design should be adaptable and modifiable, thus leading to the principle of extreme adaptability to support a long product lifespan.

Additionally, the AUD framework should facilitate stakeholders' *'collaboration'* in AT development to guarantee effective outcomes. The team configuration would rely on AT experts, volunteers, consultants, and PwIDs who actively share their diverse perspectives and collaborate on designing ATs. Previous studies emphasized the critical role of PwIDs and their families in home modification decision-making processes (Aoyama and Aflatoony, 2020). We suggest considering stakeholders' inclusion throughout the AT intervention development processes. Finally, the product developed following the AUD framework should be cost-effective and durable. We argue that ubiquity/accessibility of design tools are critical in developing/delivering AT intervention to people in need within a short time frame.

8. Potential Application Areas

In this section, we mention several application areas in which AUD might be adopted by design practitioners. We reflect on possible courses of action, augmentations, and implications.

8.1. Physical Artifacts (Structures)

In the physical realm, many universal designs have a fixed and rigid mechanical structure. Such structures are, in general, not easily adjustable. A modification may also, in many cases, not be justifiable in terms of financial cost, time, or amount of labour required. In this paper, we do not speculate on what constitutes physical materials or mechanical structures that allow for such ultimate adaptability, modifiability, and flexibility. The use of thermoplastic polymer materials for product design (i.e., AT design) might partially fulfil this requirement under the right conditions. We point out a pertinent example in another discipline of design, that of architecture. Knippers et al. (2019) describe a material-driven deformation behavior for architectural applications, which effectively results in buildings that can change their spatial configuration and shape in time, instead of remaining static throughout their lifecycle. Another possibility ("additive principle") is augmenting fixed physical structures with additions made from blue foam, wood, and other malleable materials.

8.2. Digital Artifacts

In the digital realm, typical computational capabilities comprise processors, memory, storage, input/sensors, output, and software, and as such they provide an ultimate degree of plasticity. Computational capabilities can be added to any AT product in the form of inexpensive yet powerful computational modules which allow for running customized applications, storing personalized data, and networking, such as adding a computational module featuring voice recognition, to a door designed using UD principles. Such an AUD door would then be able to open itself upon voice command recognition and activation, even to users who lack the physical ability to push the UD door open.

8.3. Artificial Intelligence (AI)

As a subset of digital artifacts, the application of AI, including machine learning (ML), holds much promise in AUD. The application of AI and ML approaches for visual impairments, has been explored previously (Morrison et al., 2017). Some possible applications and scenarios include:

- Automatically generating a high-fidelity 3D model of an AT artifact from a 3D scan of the limb and the user-supplied (textual or voice-generated) description of the disability.
- Generating a high-fidelity 3D model of an AT adaptation that is ready for 3D printing or manufacturing.

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- Training of increasingly more accurate AI and ML classifiers using large sets of samples, thus resulting in better-fitting ATs over time.
- Narrating the surroundings in real-time to assist visually impaired people using smartphones and their cameras, such as Seeing AI by Microsoft, Inc., and other applications.

8.4. Computer-Aided Design (CAD) Applications

While contemporary CAD tools already offer many operators that modify geometric objects in some way, we suggest that OTs' typical operations are specific enough that they would warrant their own (specialized) variants of said interactive operators. Specific features may include a limited number of defined operations specific to OTs making tasks, such as custom expanding, custom extending, augmenting, mounting, and grasping/holding. Furthermore, CAD application might offer appropriate interaction modalities for AUD, such as tangible user interfaces (TUIs) that use physical objects in their implementation. CAD tools might also assist OTs by offering computational and interactional features that afford user-friendly, easily accessible simulations of mechanical properties of materials that support OTs with manipulating, connecting, or repurposing objects. On the opposite side of CAD tools, we can find the "analogue" 3D modelling tools such as 3D Pens, which support hands-on creation of lines and curves in three-dimensional space, and which may prove useful in AUD as well.

8.5. Cloud Platforms

Future cloud-based platforms may offer a rich set of features and large cataloges of ready-made components and products that can be used in AUD. For instance, PwID suffering from arthritis may upload a 3D scan of her hand as well as current AT to such a platform. The platform's backend algorithms may then produce a suitable modification of the uploaded 3D AT scan, based on a description of the medical issue or disability. A dozen slightly different modified ATs, produced using inexpensive 3D printing or manufacturing technologies, could then be shipped to the PwID, who may then decide to retain and use the AT variant that has the best fit. Another useful feature of cloud platforms would be the support for online (synchronous and asynchronous) as well as offline collaboration.

9. Conclusions and Future Work

This study explored the shortcomings of off-the-shelf ATs that require post-purchase adaptation. We interviewed ten OT professionals with formal clinical training and extensive experience in prescribing/modifying ATs for people with disabilities. Our findings revealed (1) the reasons behind AT adaptation (uniqueness of patients' conditions, changes in patients' conditions, functional/economic issues); (2) Common ATs that require adaptation (low-tech, high-tech, and leisure ATs); and (3) collaborative nature of AT adaptation. Based on these findings, we identify the need for a new design approach, which we termed *Adaptable Universal Design (AUD)*, with the potential to address the perceived shortcomings of universal design approaches. Future work includes further development and refinement of AUD guidelines and associated principles.

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