Designing Inclusion

Using 3D Printing to Maximize Adapted Physical Education Participation

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Miss Garcia is a middle school physical educator who recently received a new transfer student, Lucy, who is blind. From Lucy's individualized education program (IEP) meeting, Miss Garcia knows she communicates primarily using braille. According to her parents, Lucy dislikes being physically prompted and seeks independence. Miss Garcia wants to orient Lucy to her class and wonders how she can create a tactile diagram of the unique physical space. Additionally, she would like to provide task instructions written in braille. She recently attended a training at her library about her school's new 3D printer and wonders if she could use it to print tactile and braille task cards to support instruction in physical education (PE). She remembers her librarian telling her about Tinkercad, a free online 3D modeling program, and Thingiverse, where open-source digital design files are available for free download.

The opening scenario depicts just one way 3D printed assistive technology (AT) can be used to support students participating in PE. "AT" is an umbrella term that encompasses a diverse variety of items. According to the Assistive Technology Act (2004), AT devices are "any item, piece of equipment, or product system, whether acquired commercially, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities." Reed (2007) explained that AT can be used to support the participation of students with disabilities (SWDs) in recreation and leisure pursuits, as these opportunities can improve their learning, independence, and self-esteem.

AT has the potential to improve the inclusion of SWDs by increasing, maintaining, or enhancing functional ability, participation, and learning for SWDs in recreation settings (Chambers, 2019). Students' learning and participation in PE can be supported by AT in areas including functional and communication capabilities (Laughlin et al., 2018).

> A 3D printer not only is an AT in and of itself but can be used to create AT.

Applications on handheld technology devices, like a tablet or iPad, can be used to aid in communication, modeling, and self-regulation and to promote behavior and social skills (Krause & Taliaferro, 2015). Press switches can be used to control striking machines or control the release of a ball on a bowling ramp. Adapted equipment, such as an adjustable basketball hoop or a beeper ball, may promote success in the performance of psychomotor skills. With the inundation of available AT, it is vital that teachers of SWDs become aware of options to best meet the needs of their students (Coleman, 2011).

Though AT has much potential in the PE setting, many barriers exist in accessing appropriate AT for individual students. High rates of AT abandonment have been reported due to little input from the user, difficulty with AT procurement, inadequate device performance, and changes in the user's needs or lack of individualization (Copley & Ziviani, 2004; Phillips & Zhao, 1993). Further, the cost for specialized and individualized equipment, including AT, creates a hurdle for the inclusion of participants with disabilities in school- and community-based physical activity (PA) and recreation programs (King et al., 2003; Mulligan et al., 2012). In addition, professionals have indicated the need for more information, training, and support to effectively utilize AT within PA settings (Mull & Sitlington, 2003; Rimmer et al., 2004). It is important that these barriers be overcome so that AT is provided to benefit a student's learning and participation in PE.

With the wide range of technology available, it can be overwhelming for educators to determine what can best benefit their students with budget considerations in mind. An up-and-coming technology available to most educators is 3D printing. In PE and PA settings, 3D printed AT can support the inclusion of SWDs through low-cost, highly individualized equipment creations. This article will highlight the capacity for 3D printed AT within educational settings and will illustrate how teachers, adapted PE (APE) specialists, and other related service personnel can utilize this technology to support student success in PE and PA settings. Further, this article will help practitioners locate, upload, and utilize existing collections of 3D AT models from open-source websites.

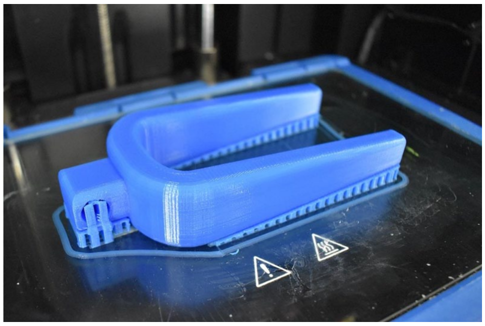
What Is 3D Printing?

Three-dimensional printing is additive manufacturing, meaning that material is added layer by layer to create a 3D model. It can be imagined by thinking about taking a tube of toothpaste and building a pyramid by squeezing progressively smaller toothpaste squares, layer by layer, on top of each other to create the 3D pyramid. Instead of toothpaste, 3D printers use filament, typically thermoplastic, that is melted by a heating element and pushed through an extruder onto a build platform called the build plate. Three-dimensional printed models are not typically smooth because of the layering, which creates ridges on the model. You will notice these ridges along the outside of the printed models formed by the layers of plastic in the figures. Like with an ink printer, digital design files containing the 3D model blueprint are loaded onto the 3D printer. A 3D printer not only is an AT in and of itself but can be used to create AT.

The inside of models, called the infill, can be chosen to increase or decrease a model's strength and weight. Infill density

> In PE and PA settings, 3D printed AT can support the inclusion of SWDs through low-cost, highly individualized equipment creations.

Figure 1 **Palm-grip pen holder on build plate with supports (Thing 1324235)**



is the percentage of plastic filling inside the model and can be printed in a variety of patterns, including honeycomb, line, recti, and other styles that best suit the shape, desired strength, and weight. Zero-percent infill would create an empty, weak, yet light model, whereas an infill of 100% would create a strong, solid model. Digital designs with overhangs and bridges require support to be printed to avoid print deforming. The image in ***Figure 1*** depicts a palm-grip pen holder (Thing 1324235) on the Dremel Digilab 3D45 build plate, with supports in the pen hole and under the handle overhangs. Once the print is removed from the build plate, the printed supports are chipped off, leaving a well-printed model to be used. Sometimes makers like to print their models on a raft, which is a layer of plastic printed on the build plate, to ensure adhesion to the plate and a cleaner print. See ***Table 1*** for a glossary of 3D print vocabulary.

3D Print Availability

Previously, accessing 3D printers required makers to send their design to specialty print shops to be printed, which could take months. Now, 3D printers are a readily publicly accessible technology located in most libraries, universities, and schools, allowing access to the greater community. Consumer 3D printers, including MakerBot, Dremel Digilab, XYZprinting da Vinci, and Prusa 3D, range in price and maximum build size capacity. With the widely available access to 3D printers, users can create their own models at reduced cost (Hurst & Tobias, 2011). Additive manufacturing allows for specialized equipment to be created at a fraction of the cost and time it can take to locate and procure AT (Buehler et al., 2016). Children and adolescents quickly outgrow sized AT; however, 3D printing has the unique ability to scale items while also reducing manufacturing time and wait time for item delivery.

Though some training is required to operate a 3D printer, those organizations and facilities housing them often have experts on-site to manage the printing aspect. If such experts are unavailable, there is an abundance of tutorial and training support across the internet. In addition, Buehler et al., (2016) suggested partnering with science, technology, engineering, and math (STEM) classes; after-school programs; and technology classes and teams as useful resources to aide in design.

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Digital design files are blueprints of the model that are typically saved as STL or OBJ files. Creators have the option to design their own models or locate an existing suitable model. Designing models can be done through the user-friendly and free websites made to support novice learners (Buehler et al., 2016), such as TinkerCAD, 123D, Blender, OpenSCAD, SketchUp, and FreeCAD. Modeling software allows for users to design blueprints of models from scratch or by importing an already-made model to be altered. The virtual design space functions like Microsoft Paint, where users can add solid or hollow shapes to create a blueprint of the desired model. Shapes can be scaled, stretched, rotated, and merged to create individualized and practical AT for specific student needs. Existing designs can be imported and modified.

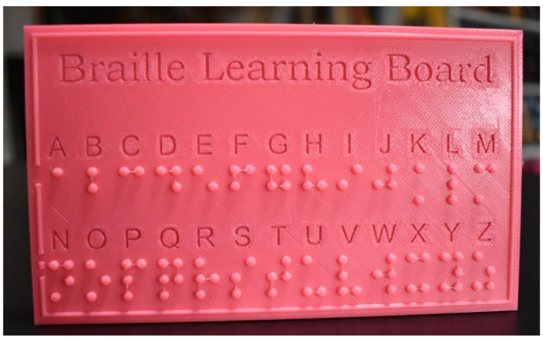
After searching through existing digital design models online, Miss Garcia finds an alphabet braille card and a yes-no choice board but nothing that looks like her gym space or a task card. She decides to give Tinkercad, an online 3D modeling program, a try and finds that it is like a 3D version of drawing in Microsoft Paint. She imports the braille alphabet and uses the letters to create task cards that Lucy can independently read (see ***Figure 2****). Additionally, she designs a tactile map of her gym using braille to label different areas. Miss Garcia then sends the files to her librarian, who prints them on the 3D printer.*

Designs can also be imported from open-source websites, like Thingiverse, Cults3D, Yeggi, Pinshape, Free3D, GrabCAD, 3DShook, STLfinder, 3Dwarehouse, MyMiniFactor, YouImagine, and SketchFab. These websites are home to databases of digital design files and are frequently open source, meaning content is available to the public. A search for words like "assistive technology," "occupational therapy," and "exercise" and names of specific sports can yield related design files applicable to PE. Buehler et al. (2015) explored the AT design community of Thingiverse and found that many designers created AT for themselves or on behalf of a friend or family member. They found that existing AT was developed to assist in activities of daily living, media accessibility, accessories

Table 1 **3D Print Vocabulary Glossary**

Term	Description
Build plate	• Flat surface that models are built upon ○ Also known as the “bed” ○ Plate size determines the max print scope ○ Must be calibrated level
Extruder	• Printer component that “squirts” out print material layer by layer • Also known as the “hot end” • Must be cleaned to eliminate carbon buildup or else jams
Filament	• Typically thermoplastic (melts instead of burns when heated) that comes wound in spools and attached to the printer as “ink” • Types and diameter vary. Common types: ○ PLA, ABS, Eco-ABS, PET, PETG, and Nylon • Other print materials: ○ Human cells, wood, metal, carbon fiber, and more
G-code	• Files are sliced into G-codes, which tell the printer which movements to make for each layer
Infill	• Selected pattern used to fill inside of model • Variety of patterns available to moderate weight and strength • Styles include grid, honeycomb, line, recti, and other patterns
Infill density	• Measured as a percentage of infill used inside the print • 0% means empty, with no infill, which creates a weak but light print • 100% means solid, with complete infill, creating a strong and heavier print
Open source	• Publicly accessible design; many 3D print model files are available online for free download on websites like Thingiverse • Preexisting models can be individualized or new ones can be designed through the free online 3D modeling application Tinkercad • Common file names: ○ STL, OBJ.
Raft	• A layer of filament printed first on the build plate located below the model • Helps ensure the first layer of the model prints correctly • Ensures model does not stick to the build plate and minimizes print deformities
Support	• Printed plastic that will be removed after printing • Used to support overhangs or bridges
Slicing software	• Converts the 3D digital design file into sliced layers and linear movement instructions in the form of a G-code

Figure 2 **Braille learning board (Thing 1275150)**



for assistive devices, prosthetics, and tools for medication management (Buehler et al., 2015).

Buehler et al. (2016) found that 3D printing promoted the creation of educational materials, such as customized learning aids, that promoted access to curricular content and found that school administrators expressed support of 3D printing in the classroom. Students with cognitive, motor, and visual impairments involved in STEM programs have participated in cocreating 3D models with the assistance of occupational therapists and teachers (Buehler et al., 2016). The capability for SWDs' involvement in designing AT can benefit individualization, student autonomy, and motivation in participation. The capacity of 3D printed AT within educational settings has been demonstrated and could realistically transfer to the PE setting.

Miss Garcia arranges a meeting with the Certified Orientation and Mobility Specialist (COMS) and the paraeducator who will be accompanying Lucy to PE to collaborate on how to best support her during class. Together, they decide to set a weekly meeting on Monday mornings before school to preteach Lucy the content and review the equipment that will be included in the PE unit. Each Monday morning, Lucy is accompanied by her paraeducator to the gymnasium, where they are joined by Miss Garcia and the COMS. There, Miss Garcia talks with Lucy and the paraeducator to review the class routine, activities, equipment, and AT that will be covered in PE in the upcoming week.

Practicality of 3D Printing in PE

Physical educators, APE specialists, and other service providers can take advantage of 3D print technology by working independently or by collaborating with on-site print experts, STEM classes, and AT designers. This technology does take some time to learn, and building partnerships and collaborating with experts is recommended. For example, Buehler et al. (2016) reviewed a partnership between occupational therapists and art instructors who were piloting a 3D printed gripping device designed for a student with limited hand dexterity. The occupational therapists found that 3D print technology had even further applicability in modifying and replacing basic AT items, like accessible clasps, custom technology cases, and custom designs, like stylus grips (Buehler et al., 2016).

Widespread access to 3D printing provides the opportunity for individualized prints, like adapted bicycle pedals, rock-climbing holds, and braille diagrams, to maximize student participation in PE. Though the possibilities are endless, four examples of 3D print models that can be used in PE are discussed next. Some additional examples of 3D printed AT on Thingiverse that are applicable to the PE setting, including a roller hockey puck, yes-no communication tiles, and a lightweight baseball bat, can be found in ***Table 2***.

Adapted Bicycle Pedal

Adapting a bicycle or tricycle for an individual who is unable to hold their feet on bike pedals due to a motor deficit improves their access to PA. Without the use of a 3D printer, adapted pedals with a single foot plate and Velcro straps can be purchased for children (Flaghouse adapted tricycle pedal, $95) or adults (Sunlite universal adapted pedal, $70) online. However, with the free, already existing STL file for bicycle pedal aids, prints can be scaled to the user's foot size, as seen in ***Figure 3***. Depending on the size of the pedal, the cost for print plastic would be less than $5. Together, the Velcro and zip ties necessary for installation can be purchased for less than $15. With an estimated cost reduction of $50 to $75, the do-it-yourself project saves money and empowers individuals to adapt equipment to their needs on their terms.

Tactile Models

Teaching health-and-wellness content in PE can be supported with anatomical models of the cardiorespiratory system. Anatomical models are historically expensive and specific to science-based classes. In PE, anatomical models can be used to demonstrate how joints function as levers with the power of muscles, how the lungs oxygenate blood, the skeletal system, and many more bodily functions that allow us to engage in PA. This anatomical heart model shown in ***Figure 4*** could further benefit a student who is dependent on visual and tactile learning and could allow a student with a visual impairment feel the anatomy being discussed.

Further, tactile models can include diagrams and maps of physical spaces, allowing students with visual impairments to orient to their activity area and develop an understanding of positioning. Tactile diagrams of a soccer field, baseball field, tennis court, running track, or swimming pool are examples of ways a teacher could help a student with visual impairments orient to their activity area with a guiding map that they can feel. Designing a tactile layout of the school could facilitate the independence of a student with visual impairments during transitions.

After Lucy orients herself with the tactile diagram, the group takes a tour around the gym while Lucy locates the braille task cards and reviews the 3D printed instructions. During this time, Lucy is encouraged to ask questions, provide suggestions on the equipment being used, and advocate for her needs.

When Lucy joins the class, Miss Garcia hands her the tactile diagram. When the lesson begins, Lucy knows to find the task cards on the wall with braille instructions of the skills practiced earlier. With the support of preteaching and her paraeducator, Lucy can successfully participate in PE activity along with her peers.

Tactile Braille Dice

Large rolling dice are frequently used within PE activities to randomly select exercises, determine order, designate position, and motivate participation. The tactile dice featured in ***Figure 5*** is universally designed to include braille for students with visual impairments and can be scaled up or down to best suit a student's grip or hand size. Commercially available braille dice range from $10 to $30, whereas a 3D printer can quickly produce this product for less than $5. Existing exercise dice models listed in ***Table 2*** can be modified with braille translations and with class-specific exercises by importing the model into Tinkercad. Additionally, students' names could be added to dice to by the teacher to pick order, assign groups, or designate position.

When Lucy's class tosses foam rolling dice to determine the number of warm-up exercise repetitions to complete, Lucy's group uses braille dice to determine their repetitions so that Lucy can complete the warm-up along with her classmates.

Printed Grips

Bueler et al. (2016) found that occupational therapists were able to cut down an estimated 2 weeks of wait time from custom-ordered AT from catalogs and manufacturers by using and altering already-existing 3D models, which resulted in cost cutting and individualized grips for their students with limited dexterity. Students might participate in a

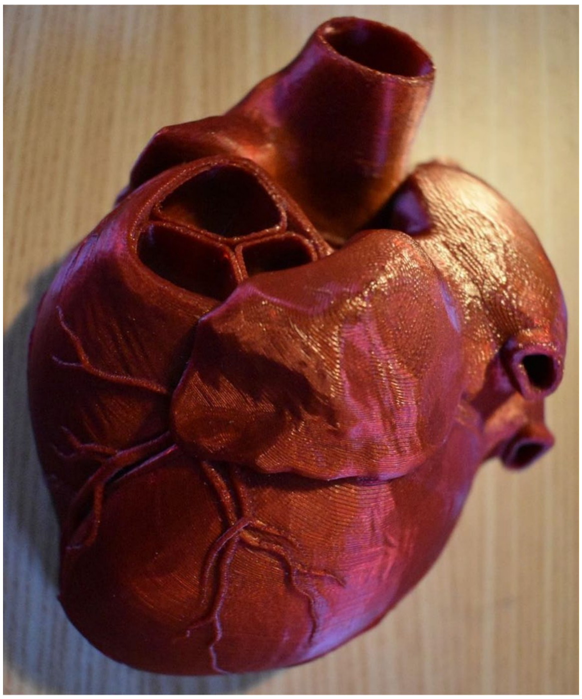
Table 2 **Examples of Assistive Technology Designs Available on Thingiverse**

Assistive technology	*Thing number (https://www.thingiverse.com/thing:#)*
Desktop air hockey mallet	14068
Desktop sports	626727
Dumbbell	2756194
Dumbbell fat grips	2203950
Exercise dice	2130495, 3431742
Full-scale customable bowling ball	3347470
Golf ball returner	2315025
Golf hole	966464, 2858712
Jump rope	372103
Lightweight or small baseball bat or tactile baseball bat	2002860
Miniature golf putter	443799
Over-the-door shoulder exercise pulley	2789310
Press switch	2507266
Pull handles for exercise band	189991
Roller hockey puck	384172
Screw-top hockey puck (add bells)	792525
Tabletop bowling	2935578, 4334534
Tabletop soccer or hockey goal	677905
Tactile braille dice	1522413
Tin can dumbbell	18249
Walker basket hook	3844984
Walker cupholder and hook	2838432
Wheelchair clamp	856639, 856635
Wheelchair device mount	1104680
Wheelchair footrest	3457152
Wheelchair suitcase hook	3650628
Writing grip	4612932, 1058000, 1324235, 2802077
Yes-no communication tiles	1726685

writing task in PE to document health-related goals, fill out self- and peer assessments, or keep score. Adaptive pencil grips and holders, like those featured in ***Figures 6*** and ***7***, are examples of 3D printed AT that could help students who have difficulty with fine motor control, limitations in muscular function, tremors, or limited range of motion complete a task requiring a written response. Although writing utensil grips are commercially available for purchase, ranging from around $5 to around $20 or more, a 3D printed model may be more cost-effective and also allow the student to

Figure 3 **Adapted bicycle pedal (Thing 1560036)**

Figure 4 **Anatomical heart, frontal plane with four-chamber view (Thing 942464)**



select from a variety of individualized tools to find one that works best.

Similarly, striking implements could be modified with a ball or hook grip to facilitate a student's participation. A printed handle could be added to a hockey stick, baseball bat, tennis racquet, or other striking equipment to allow a student with fine motor deficits or limited hand dexterity to hold on. The dumbbell fat grips (Thing 2203950) listed in ***Table 2*** could be modified to a specific fit that utilizes an SWD's abilities and used on a variety of striking implements.

Fidgets and Manipulatives

Physical educators have reported challenges in managing behaviors of students with autism, including emotional regulation, hyperactivity, and impulsivity (Zhang & Griffin, 2007). Zhang and Griffin (2007) discussed and encouraged physical educators to create and select equipment based on the sensory interests of children with autism. A PE teacher using 3D printing could design unique models, like fidgets and manipulatives, that appeal to a student's dominant sensory interests.

Fidget toys are often given to students to occupy their hands while receiving instruction or waiting their turn, as a reward, or to aide in transitions. The recent fidget spinners fad was picked up in the Thingiverse community and expanded to include a wide variety of fidget models. One line of design called "flexi prints" comprises shapes—commonly, animals—that are designed with a series of articulated hinges to allow for movement within the model. Featured in ***Figure 8*** is an articulated flexi giraffe (Thing 3623536) printed for a student whose favorite animals are giraffes. Other flexi designs include dinosaurs, unicorns, lizards, sharks, dragons, skeletons, alligators, and many more. Like with previous examples, the articulated hinge component can be imported into Tinkercad and used to design a student-specific fidget with their favorite animal, their name, or their favorite shape. Further, searching "fidget" on Thingiverse populates over 500 pages of custom fidget designs. Beyond occupying a student's busy hands, fidgets can be used to develop fine motor control, develop emotional regulation, and motivate student activity by appealing to individual interest.

Clamps, Levers, and Attachments

Wheelchairs, walkers, and other mobility devices can be adapted with individualized clamps, levers, and attachments that can help to bridge gaps in accessibility. Currently existing 3D printed wheelchair and walker accessories, like technology device mounts (Thing 1104680), cupholders (Thing 2838432), carrying hooks (Thing 3650628), and clamps (Thing 856639), have the potential to be used or altered for individual student need. A wheelchair or walker could be adapted with 3D printed articulated mount or clamp to hold striking equipment, like a tennis racket. An

Figure 5 **Tactile braille dice (Thing 1522413)**

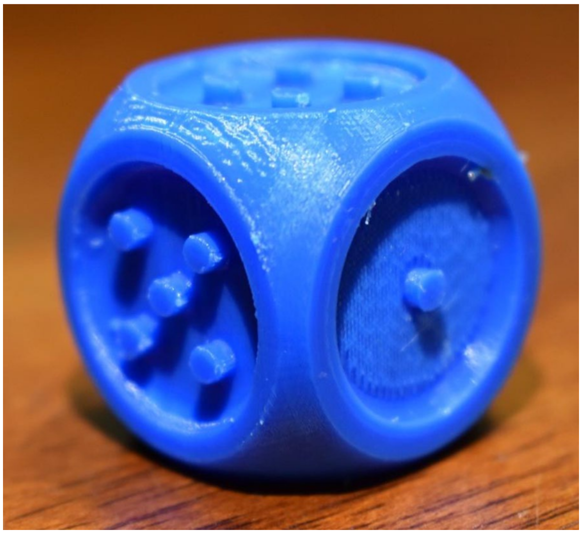
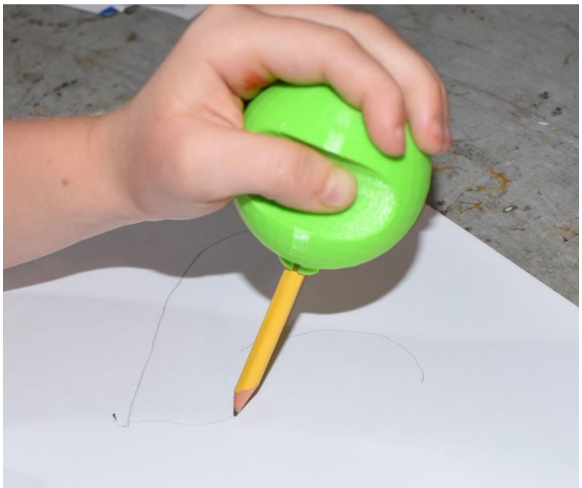


Figure 6 **Left-handed pinky/thumb adapted ball pen (Thing 4612932)**



> Before the unit begins, teachers should orient students to when, where, and how AT will be implemented in the unit so that less time is spent giving instructions and clarifying and more time is spent included in class activities.

articulated or hinged mount can create a lever that permit students to swing or strike using minimal force and movement. Time spent chasing projectiles can be minimized with attachments like the walker basket hook (Thing 3844984), which can allow students to carry equipment, like balls. Printable wheelchair footrests (Thing 3457152) can be modified by adding a striking surface in the form of a front-facing plank to hit a low-approaching ball for SWDs to participate in sports like soccer and kickball.

Suggestions

Although 3D printing can be useful, it is not a solution on its own. By collaborating with those involved in a student's education, PE teachers can best prepare themselves for possible modifications and gain insight into the student's preferred learning styles. PE teachers often feel more prepared to include SWDs when given administrative support and time for planning and preteaching (Conroy, 2012). To successfully integrate 3D printed AT in PE, teachers need to consider planning, collaboration, and student empowerment (Chambers, 2020).

Preteaching

PE teachers can collaborate with COMSs, paraeducators, special educators, guardians, or peer tutors to convey specific goals for preteaching along with the objectives of the unit (Block, 2016; Conroy, 2012; Perkins et al., 2013). Preteaching prepares SWDs before PE by teaching activity perimeter, names of skills, positions, objectives, rules, scoring, equipment used, and levels of competition (Block, 2016). Preteaching should include equipment and AT that students will use in the upcoming unit. Before the unit begins, teachers should orient students to when, where, and how AT will be implemented in the unit so that less time is spent giving instructions and clarifying and more time is spent included in class activities.

Self-Determination

SWDs are frequently excluded and marginalized in school, especially in the PE classroom. Teachers report concerns about students' risk of injury or risk or injuring a peer, which create barriers to

Figure 7 **Palm-grip pen holder (Thing 1324235)**

Figure 8 **Articulated flexi giraffe fidget (Thing 3623536)**

the inclusion of SWDs in PE (Haegele & Zhu, 2017; Lieberman & Childs, 2020). Self-determination is an important factor to consider when including SWDs in PE and in community-based recreation and leisure experiences (Bullock & Mahon, 2017) and can be enhanced through decision-making opportunities related to AT use. PE teachers should promote the self-determination of SWDs by encouraging them to express their opinions, practice decision-making skills, advocate for their right to participate, and provide suggestions relevant to their individualized needs. For example, SWDs should be provided with options and encouraged to make autonomous choices regarding the AT and equipment they want to use in the PE setting. Providing opportunities for students to make decisions for themselves can lead to greater sense of empowerment (Bullock & Mahon, 2017).

Involving students in the design and selection of 3D printed AT can benefit the utility of the model and provide experience communicating personal needs. Students' involvement in the design and selection of AT can lessen the risk of abandonment by increasing investment and encouraging self-advocacy. Teachers cannot assume that just because AT was provided, it is benefiting the students. Students' involvement in the design of AT is as important as their feedback on its utility. PE teachers should create opportunities during the planning-and-design phase and during and after the AT use in the classroom. Incorporating SWDs' decision making into the planning and evaluating process of implementing AT can develop self-determination through self-advocacy, decision making, and problem solving.

Conclusion

This article discussed the capacity for 3D printed AT within the PE setting and illustrated how physical educators, APE specialists, and other related service providers can take advantage of 3D print technology. The potential of 3D printing has been demonstrated in other areas of education and should be considered for use in PE to promote the inclusion and participation of SWDs. The wide adoption and availability of 3D print technology in universities, schools, and libraries makes this a feasible and cost-cutting option. By utilizing open-source digital design files and free modeling software, physical educators and other professionals can design individualized AT specific for their students' needs.

Further, preteaching students to familiarize them with AT before the PE unit will lend to their success in class and can provide opportunity for self-determination and student empowerment.

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