"Piece it together": Insights from one year of engagement with electronics and programming for people with intellectual disabilities

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Figure 1: An electronics and programming package for people with intellectual disabilities consisting of TapeBlocks, Blue-Bot, and Sphero. These technologies were used in combination with common craft materials to explore making of unique artifacts and creative experiences.

ABSTRACT

We present the results of one year spent engaging people living with intellectual disabilities with an electronics and programming package. The program was run in collaboration with a disability support organization and delivered by support workers. We evaluate key qualities of the package at three sites via ongoing communication and reflective interviews with five support workers, along with observation of sessions and contextual inquiry with eleven people with a range of disabilities. Our findings demonstrate the importance of physicality in enabling experiences by creating real-world analogues and supporting diverse group interactions; how groups support members' attention, motivating each other, and allow space for coping mechanisms; and participants' growing confidence and creativity in problem solving, and the emergence of self-directed activities. We discuss the importance of diverse repetition for skill development, how skills develop over the year, and pragmatic lessons for conducting a long-term research program with a disability support organization.

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CCS CONCEPTS

• **Human-centered computing → Accessibility technologies**.

KEYWORDS

Accessibility, intellectual disability, making, toolkits, tangibles

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1 INTRODUCTION

People with disabilities face many barriers in engaging with technologies that enable them to create and control hardware and software. The maker movement, computational toolkits and consumer bots have expanded the cohort of people who are able to engage in these activities, but there has been limited research on their use with people who have intellectual disabilities.

In this work, we address the lack of programs for people living with intellectual disabilities through the creation and deployment of a Science, Technology, Engineering, Art and Mathematics (STEAM) package comprising of a set of accessible electronics and robotics toolkits (Figure 1). It was designed to teach a range of skills to enable the creation and control of technology for a group of cognitively diverse adults that participate in support programs. It uses the creative exploration of the natural world as a basis for developing basic electronics and programming skills.

The opportunity to actively create and control technology is a critical skill in many modern environments and economies, but access to opportunities to develop the skill is not equitably available [56]. Reviews show that individuals with intellectual disabilities are excluded from developing STEAM skills in school [63] due to lack of teaching expertise [29], financial barriers [47], time constraints [25], and toolkit/resources [47]. Learning these skills is inherently rewarding because it helps them better understand and actively participate in the environment they live in. Moreover, it offers a route to self-esteem and competency [5, 64] by helping them productively spend their time making projects that others can enjoy and which enrich their lives.

With care, accessible designs can open up electronics and programming for excluded groups as seen in toolkits supporting the teaching of digital skills to people who are visually impaired [3, 26], those living with physical impairments [48] or people living with a range of age-associated healthcare challenges [20]. However, toolkits focused on cognitive challenges are less common [45]. The process of teaching STEAM-related making relies on cognitive capacities including long term memory, concentration, and abstract thinking [30] and programs typically cannot adapt when one of these areas is more challenging for a participant. The STEAM package we developed approaches this challenge by identifying key accessibility qualities that would support our target population and combining existing toolkits to meet their requirements. We are hesitant to claim the package we use will be accessible to everyone who is currently excluded from digital skills—however, we focus on limited cost, physically grounded teaching, which is relevant to other excluded groups [51].

Our STEAM package was created at the request of a local Disability Support Organization (DSO). The DSO is a social enterprise that supports adult clients living with disabilities that affect cognition ranging from intellectual disability, Down's syndrome, autism spectrum, or pervasive developmental disorder. They also cater for clients that have additional physical disabilities. Professional disability support workers assess their clients' learning needs and teach them new skills. These full-time coaches come from a range of backgrounds including disability support, individual support, and allied health and teaching. The DSO coaches run day programs that range from learning activities on topics such as money management skills to physical activities like swimming and enrichment activities like sailing. The groups they run vary in size depending on client needs from 1-1 settings up to 1 coach to 4 clients. Our partnership went beyond providing the toolkits in exchange for evaluation. We aligned our design, evaluation, and thinking with the DSO, creating interventions for their clients that would expand the experiences available to them and producing materials that could be understood and delivered by their coaches. This meant considering common challenges in the group - discussion with coaches led us to consider challenges in: short-term memory, manual dexterity, emotional regulation and patience, literacy, speech, attention, reasoning, and long term memory and retention. Our role was to provide concepts, training and resources to the DSO coaches and then give them time to introduce the concepts at a pace and in a way that was suitable for their clients. We acknowledge that more tailored solutions for specific disabilities could be needed, but as the DSO we partnered with did not make distinctions based on specific conditions, our package could not either.

Our aim was to facilitate and increase participation in STEAM enrichment activities for people with intellectual disabilities through an electronics and programming package that is supportive of their and their DSO coaches' needs. We wanted to examine the deployment of this package over the long term to better understand how it was used by both DSO staff and clients. To this end, our contributions are, 1) identification of key attributes in electronics and programming toolkits that is supportive of adults with intellectual disabilities and the design of a package for STEAM engagement that can be deployed independent of researchers over a sustained period of up to 200 hours; 2) findings from observation and contextual inquiry at three sites with five coaches and eleven clients working on the enrichment activities for up to 12 months; 3) discussion of the lessons, including the pragmatic and methodological challenges for researchers in this field, and the relationship between ability and time scale when deploying STEAM programs of this kind.

The benefit of this research is that it includes people with intellectual disabilities in the making of technology. Additionally, it demonstrates the capacity of this user group to drive personally meaningful electronic projects.

2 RELATED WORK

We examine the lessons in previous work that specifically look at introducing electronics and programming to people who live with intellectual disabilities. As the literature in this area is sparse, we also consider efforts to make the Maker movement more inclusive, and the toolkits aimed at teaching programming skills to children.

In this paper, the use of the term intellectual disability reflects the terminology used in Australia and the DSO we worked with. All of our workshop participants had diagnosed intellectual disabilities which are defined in Australia as cases where a person shows *"difficulty learning or understanding things"* for longer than 6 months and who often have other physical coordination problems [19]. Intellectual disabilities are characterized by deficits in reasoning, problem solving, planning, abstract thinking, judgment, academic learning, and learning from experience [2]. Our work is also informed by literature and experiences working with people with traumatic brain injury which causes various cognitive issues including memory loss, aphasia and problems with long term attention [46].

2.1 People with intellectual disabilities learning programming and electronics

Teaching electronics or programming to people living with intellectual disabilities frequently hinges on the use of tangible elements. For example, a group of students with intellectual disabilities and a group of students without intellectual disabilities were taught to program a robot to move in a square, through explicit instruction using Blockly, an iPad application in a 2017 study [55]. Although the students learned at a different pace, both groups were capable of programming the robot. Another case study found it was possible to teach computer programming to early elementary students with Down syndrome, though the study had many limitations that were highlighted as future research opportunities [57]. Other small scale studies have reported on students with Autism Spectrum Disorder and developmental disabilities having success with pre-coding or coding skills to manipulate a robot's activity [33, 56, 57].

The "LittleBits go LARGE" project was undertaken to counter the current electronics kits which demand a high level of understanding, such as Arduino. They simplify the conceptual and motor capabilities required for making circuits by joining parts using snap-together magnets [27]. The TapeBlocks toolkit reported similar success in stimulating creativity and engagement for people with intellectual disabilities by using large foam blocks with conductive tape to reduce the demand for fine motor skills [21]. The work also explicitly addressed a gap by providing toolkits that are economically viable as well [21]. The application of robotics to engage students with disabilities has also been examined by Knight et al. who reported that the student they worked with was able to learn new coding skills and generalize them [33].

Beyond physicality, providing explicit instruction to teach individuals with intellectual disabilities, in contrast to a constructionist teaching approach that is often applied in teaching programming, has shown promise [29, 56]. Setting up scaffolding, creating prompts that have visibility, and limiting the need for large amounts of memory recall have been identified as ways to help students with intellectual disabilities engage with technology [15]. Work in this area is limited in scale and scope. Further research is needed to determine suitable approaches to open up programming, robotics and computational thinking and improve the outcome for underrepresented groups [23].

2.2 Opening up the Maker Movement and Makerspaces

The Maker Movement provides clear motivations for including people with disabilities, showing how they can experience the empowering potential of makerspaces [9, 42, 58]. Participants have detailed how they saw the relevance in learning maker skills for expanding their own abilities to make self-directed accessibility hacks, harnessing their skills for helping others or achieving recognition by showcasing their maker expertise [42] while the maker communities themselves report eagerness to help [9, 58].

The Maker Movement has had successes with toolkits utilizing accessible micro-controllers, sensors, actuators, and 3-D printing capability, enabling students to learn in ways that were previously unavailable [16]. Existing work on introductory toolkits for making has primarily focused on an able-bodied population with good vision and fine motor skills [6, 12, 49]. However, the maker movement has a long history of attempting to be open but struggling to include classically excluded groups [58]. This creates major barriers to entry for people with disabilities, specifically those with intellectual disabilities, as underlying health conditions often result in limited dexterity [22] and most of the components of these toolkits are small and difficult to manipulate. Work to date on accessible technology design focuses on those with motor, hearing or visual impairments [45] and Chapkol et al. [17] indicate a need for the development of applications that focus on the user requirements of the neurodiverse. Their research builds upon previous research which has explored the numerous barriers to makerspace accessibility [21], and previous efforts to make electronic and maker toolkits more accessible [3, 12, 27, 43]. Ultimately there is a need to bring people with disabilities into design communities and STEAM focused hobbyist spaces at a social and cultural level, and this is equally as important as making the tools and spaces accessible [13, 58].

2.3 Teaching programming to diverse audiences

Work in education has the longest history of considering how electronics making and programming can be opened to excluded groups. Coding is a basic skill that all students should learn [30]. Teaching coding at an early age to children has been found to assist with their problem solving abilities, analytical skills and help with the development of collaborative abilities and creativity[24, 31, 41]. Two recent reviews on the evolution of introductory programming in education research provide a comprehensive account of key developments in the field. The first review had a focus on introductory programming or Computer Science 1 (CS1) level papers, by Becker and Quille [7] and categorized 481 papers from SIGCSE symposiums that spanned over five decades. The review identified that topics such as making, learning, programming from gender, diversity, accessibility and inclusion perspectives, grew in significance over this period [7]. The second is a systematic review undertaken by Luxton-Reilly et al. and presents an overview of the introductory programming literature for the period 2003-2017 [39]. The research examining issues surrounding the lack of student diversity in computing grew from the period 2005 onward, with the initial focus being on gender diversity, and later reference is made to a noticeable lack of research on teaching programming for students with intellectual disabilities or cognitive impairment.

Even though tools have been developed for blind and visually impaired students to learn programming, there are several programming languages that are not user friendly because they do not provide auditory support or screen reading [18, 26]. Programming languages using physical blocks or pods to represent a command are more accessible, as each block can be distinguishable by touch and help to address the accessibility barriers in learning programming for people with visual impairments and other learning disabilities [1, 52].

3 STEAM PACKAGE

This research was initiated by an invitation from the DSO to develop a long term STEAM program to be delivered weekly across multiple sites as part of their day program offerings. The aim was to have this program delivered by their coaching team.

3.1 Prior work with DSO

Previous work with the DSO has explored single and short-term workshops with different electronic toolkits for people with a range of intellectual and physical disabilities. These include 6 workshops with a total of 148 participants with a range of support requirements, including assistance with communication and fine motor co-ordination. This comprised 8 high support participants that required 1 participant to 1 coach, 16 moderate support participants with 2 participants to 1 coach and 124 low support participants with 4 participants to 1 coach. The workshops ran for 45 to 90 minutes and catered between 4 to 45 participants at a time, with activities including accessible electronics, modeling, and control of robotic balls [53]. These workshops informed the selection of toolkits for the STEAM package and helped identify the key characteristics for building skills with the target population.

Other work with the DSO has also examined the support staff's perspectives on integrating electronic toolkits into their practice [21]. Remote maker workshops conducted by support coaches helped evaluate toolkit design issues with young adults living with intellectual disabilities [21]. These workshops not only informed STEAM package selection but also helped address some of the pragmatic concerns surrounding deployment.

3.2 Key qualities

Based on this prior work, we identified six key qualities with the aim of building skills and sustaining the interests of clients over a long program. The intention was to provide activities that were challenging and accessible to participants with intellectual and physical disabilities without being difficult enough to induce anxiety. To better illustrate the key qualities within the context of the STEAM package, we briefly describe the three physical electronic toolkits chosen for deployment. The package included TapeBlocks[1], electronic foam blocks wrapped in conductive tape that can be pushed together to form connections [21]; Spheros[2], a robotic ball that can be controlled via a smartphone or tablet; and Bee/Blue/Rugged Bots[3], a set of programmable floor robots designed to be directly controlled by their on-board command and program buttons. A more detailed description of the individual toolkits is provided in subsection 3.3. These toolkits embody different aspects of the key qualities discussed below.

3.2.1 Diversified repetition. The DSO clients we worked with found repetition to be particularly important when learning a new skill. Moreover, many of them shared the capacity to maintain focus on a repetitive task for long periods of time without becoming bored. This was seen in sessions where participants would build small variations of an item for several hours, and across sessions where participants enjoyed revisiting an activity, they knew how to do well. Thus, we selected toolkits that allowed repetitive work with small variations to support these extended periods of attention and promote skill development. TapeBlocks embodies this quality since it allows clients to spend several hours crafting blocks to represent different characters, people or artifacts with slight variations.

3.2.2 Simple interoperability. We found that many of our earlier making activities with the clients were part of an ecosystem of other consumables, craft materials and technologies. Consequently, we aimed for simple interoperability between the toolkits to enhance their expressive power. With the package we developed, clients can make the individual toolkits interact with each other in novel and interesting ways. For example, the Sphero or BeeBot could be driven around a course made up of stacked illuminated TapeBlocks. Knocking one of the blocks over will break electronic connections thereby switching the LEDs off. Thus, participants can visually see the outcomes of their programming. The kits can also be used with other consumables. For example, ramps could be built out of cardboard to race Spheros.

3.2.3 Low manual dexterity thresholds. Since the clients had varying physical abilities, we chose toolkits that required minimal physical dexterity to manipulate and program. However, each of our toolkits had a number of options available for facilitating interaction both physically and conceptually. For example, the Sphero could be driven via a finger on a touch screen, but also allowed for a more detailed path to be drawn for custom paths. Similarly, TapeBlocks could be pushed together on a table to create electrical connections but could also be stacked in different configurations to create 3D electronic artifacts. The BlueBot could be programmed via simple button pushes on the device itself or through Bluetooth from a phone.

3.2.4 Supporting community and individual activities. During our initial workshops and making experiences, we found that clients sometimes enjoyed working together collaboratively and at other times working alone in a two hour session on a specific idea they had in mind, slowly iterating or building small variations on the same item. The ability to determine their level of interaction with others was supported by the toolkits we had shared with them. Clients would come together around more complex tasks using multiple toolkits to simulate cars driving around a city or create characters individually. Consequently, in our STEAM package, we paired toolkits to support both community and individual activities. This further ties in with the quality of simple interoperability between toolkits.

3.2.5 Building towards personal meaning. Although our initial work with the clients was short in duration (when compared to our present study), we observed clients gain a degree of mastery over materials and toolkits over time. This led to small goals and eventual steps towards them. Of particular importance was being able to link the activities back to areas of relevance to their everyday lives including current affairs, special interests, personal items and hobbies. We found that independent generation and directing of ideas for activities increased personal meaning in the outcomes.

[1] https://www.tapeblock.com
[2] https://sphero.com
[3] https://www.tts-international.com/primary/computing-ict/our-floor-robot-family-bee-bot-others/

3.2.6 Language independence through physicality, embodiedness and choice. Verbally describing technical challenges was not possible for many of the clients we worked with as they were either non-verbal or did not enjoy talking to communicate. However, it was evident that the clients wanted and needed to communicate. Thus we selected toolkits that, through their physicality, could allow them to show what they had done or the problems they were encountering. For example, a step in the programming of a BeeBot that wasn't working as intended could be shown by running the BeeBot and pointing to the place it started to go awry.

3.3 Detailed description of the toolkits

As alluded to earlier, three toolkits were supplied to each of the DSO sites. These were TapeBlocks, Spheros and Bee/Blue/Rugged Bots kits. To support the program, the coaches were provided either in-person or online training with a researcher (see section 3.4). Each individual toolkit included in the package came with enough units such that all participants could use the same technology simultaneously (e.g., four participants had access to at least four Spheros or BeeBots). The packages were supplemented with consumable craft items from the DSO such as colored paper, glue and scissors, and consumable items such as cardboard and wooden boards.

Much of the equipment (e.g., Sphero, BeeBots) we supplied was for group use and had to stay on-site but the artifacts created using consumables could be taken home by participants (for example TapeBlock characters and Sphero paintings).

3.3.1 The TapeBlock Kit. This kit was provided to enable engagement with electronics activities. TapeBlocks are a chunky electronics toolkit made out of foam blocks, conductive tape and electronic components. The kits themselves can be used in a variety of ways with varying levels of complexity. The simplest use of TapeBlocks is to make circuits with pre-made blocks by combining and stacking power, sensor and actuator blocks. The pre-made blocks include power, light-emitting diodes (LED), vibration motors, fans, buzzers, buttons, tilt switches, and light dependent resistors. It is also possible to make customized TapeBlocks from electronic components by attaching the components to foam blocks with conductive tape. The blocks can be stacked to create 3D electronic objects such as a lighthouse. TapeBlocks can also be use to make creative artifacts such as animals and characters when combined with other craft materials. Craft materials including fur and craft eyes were also included in the kits.

3.3.2 The Sphero Kit. The Sphero is a clear, round, programmable robot ball that can be controlled by programming or driving it on an app. It can be used to facilitate activities that require navigating through obstacle courses or can be used creatively to make moving puppets. The simplest method to drive a Sphero via an app on the phone is by aiming and then moving a finger on a touchscreen. The speed and color of the device can be customized by the user. It is also possible to direct the ball by creating a visual program on a touch device that records the path for the Sphero to travel and then replaying the program to drive the device along the recorded path. The final method for driving the Sphero is through a block-based programming app where more complicated sequences of movements can be programmed.

The Sphero kit included at least one Sphero for each participant, a charging station, and accessories such as ramps for jumping and cups to be used for creating puppets. One phone was provided that was loaded with the Sphero controller app for each site and the DSO provided iPads.

3.3.3 The Bee/Blue/Rugged Bot Kit. This kit consists of small robots that can be controlled and programmed directly by pressing buttons on the body of the robot. Unlike the Sphero, these Bots do not require an external device to program although they can use one. The Bot devices can be used for programming a path and navigating mazes. They can also have accessories that enable drawing on large sheets of paper by attaching a pen to them and can be used for creative activities including puppet making. A Bee Bot looks like a bright yellow beetle that is slightly larger than a tennis ball. The Blue Bot looks very similar to the Bee Bot but has a clear case. The Rugged Bot is larger than the Blue/Bee Bot and is similar to a remote control car. Each of the devices have four directional arrows, a go button, clear and pause buttons. The eyes/headlight on the device light up and they have a range of beeps to indicate different states and statuses. The Blue Bot and Rugged Bot can also be connected to other devices for programming via Bluetooth.

The Bee/Blue/Rugged bot kits included at least one device for each participant. We also included accessories such as pen holders (to make custom drawings) and bulldozer attachments for the Bee/Blue bots. Cards and mats that had directional arrows were also provided to facilitate custom path building. A docking station along with cables for the devices were provided at each site.

3.4 The Coach Training Program and Reference Website

We provided DSO coaches with training on how to use the toolkits through either in-person or online sessions. Each training session was approximately one hour in duration with two to three coaches. We provided demonstrations of the toolkits and gave sample activities they could conduct with the clients. The training sessions emphasized how coaches could be creative in presenting the toolkits and adapting activities to meet the needs and interests of the clients. In addition to the training sessions, we provided a website with detailed videos on the equipment required for different activities and the basic instructions on how to use each toolkit. Although many of the videos were created and produced by the research team, we also linked to external resources to provide ideas for activities.

4 METHOD

We assessed experiences with our educational STEAM package through an ongoing deployment at three of DSO's sites that, by the final meetings reported here, had been using the package for between four to twelve months. After training, the STEAM package was left with the sites and coaches to use. Clients used the STEAM package for between 36 and 200 hours at this point. Support from the research team was offered over email and phone for coaches when toolkits broke, items were lost, or when they wanted to try and create their own packages of activity with it. During this time, we returned to the DSO to observe sessions and interview coaches several times. We worked with five coaches and eleven clients to understand the efficacy of the toolkit, how rewarding it was to use and how it could be improved in the future.

We assessed this through 1) ongoing communications with each coach supporting their sessions including viewing videos and photos of the activities; 2) observational studies of a session at each site augmented by contextual inquiry with the clients and coaches; and 3) reflective interviews with the coaches after the observed sessions where they were invited to reflect on our analysis of the sessions.

Ethical approval for the work was gained from our university ethics committee and from the DSO group. Informed consent was obtained from all participants including those who dropped into single sessions with written information sheets, video and verbal explanations. Participants were able to withdraw from the program at any time and, whenever recorded for analysis, we made it clear they could ask to be excluded from the video and still take part in the sessions.

4.1 Research environment

The DSO supports approximately 500 clients with disabilities in the outer suburbs of a large Australian city across a range of services. The people require support because of various physical and cognitive disabilities including intellectual disability, acquired brain injury, Downs syndrome, autism and cerebral palsy. The services that they offer include residential services, support with daily living, educational opportunities, community engagement and supported employment. This research was conducted as part of their day program offerings that provide educational (e.g. money skills and literacy), physical (e.g bowling and swimming) and social engagement opportunities (e.g. disco) with the low support group (four clients – one coach). The research collaboration was facilitated through the DSO Education Manager in conjunction with the site managers of the day services. The DSO undertook the recruitment of participants and managed logistics such as scheduling and transport to the venues for participants which are part of their normal practice. Over the year that the program has run, some coaches have left or moved within the organization.

4.1.1 Recruitment and program initiation. Our program was advertised to the DSO clients as a new STEAM course, alongside more than 30 other programs that the DSO offers. Our STEAM program was offered at three sites (Table 1). The equipment was delivered to sites and was demonstrated to the coaches during a training session by the researchers that ran for approximately one hour. Clients were able to sign up to programs at any stage. The participants in the program had a core group that attended every week but the groups were fluid as other clients would join in if their other activities were canceled. Different sites ran sessions for different durations, ranging between two to five hours depending on the clients needs, preferences and site availability (Table 1). The sessions were run in large, well-lit, classroom-like environments with movable tables and chairs, clear floor spaces, and low fidelity making equipment such as cardboard, paint, glue, string, etc. Different sites began to work on the program at different times depending on their timetables and the interests of participants. Our assessment took advantage of this to capture different amounts of time with the STEAM package.

4.2 Participants

4.2.1 Clients. All of the participants were current DSO clients with experiences participating in other courses the DSO offered (Table 2). The clients exhibited a range of skills and abilities. Some clients had limitations in their ability to process information, follow instructions, concentrate for longer periods, verbal abilities, fine motor co-ordination and repetitive behaviors. The diagnosed disabilities of participants included autism, cerebral palsy, Downs syndrome, hearing impairment and non-specific intellectual disability. None of the participants reported previous experience with computing, electronics or making.

4.2.2 Coaches. Four of the coaches had been working in the disability field for more than five years in a range of roles and one coach had only started working in the disability field when they started coaching in the program (Table 3). The Site 1 coach had a background as a mechanic and engineering in the telecommunications field. None of the other coaches had any previous experience in teaching programming, electronics or making.

4.3 Data Collection and Analysis

The clients we worked with had a range of communication abilities. All of the participants were able to understand and follow instructions but, while some participants had good verbal communication skills, others used body language and gestures to communicate. Prior work established the need for a flexible approach in educational work with disabled students [60] and we agreed with the DSO coaches that interviews were not an appropriate method to understand their experiences with the STEAM package. We drew on research that shows the potential for video recording [61] and contextual inquiry with people living with cognitive disabilities [37] to help document and understand participants' experiences. Video allowed us to capture a diverse set of interactions while contextual inquiry allowed clients to explain their work non-verbally *in situ*. In this way, the context they needed to draw on to explain their ideas can be pointed to without arduous verbal explanation. With this in mind, we collected data in three ways.

Site	No. of participants	Sessions with package	Observation session(s)	Typical duration	Total time
Site 1	3+1	40	4, 16, 24, 40	5 hours	200
Site 2	4+1	26	6, 24	5 hours	130
Site 3	2	18	8, 16	2 hours	36

Table 1: The different DSO sites we ran deployments at, number of regular participants per site + number of drop-ins or one participant for a single session we observed, and their experience for a number of sessions, number of observations by the research team, typical session duration, and total hours spent with the STEAM package.

Client	Pseudonym	Site	Age	Gender	Disability
1	Kayleigh	Site 1	26	F	Intellectual Disability
2	Mary	Site 1	26	F	Autism Spectrum
3	Mark	Site 1	26	M	Cerebral Palsy
4	Noah	Site 2	24	M	Autism Spectrum
5	Abdul	Site 2	19	M	Autism Spectrum
6	Leigh	Site 2	20	M	Autism Spectrum
7	Lalya	Site 2	23	F	Hearing and Intellectual Disability
8	Sahib	Site 3	29	M	Intellectual Disability
9	John	Site 3	26	M	Down's Syndrome
10	Fiona	Site 1 Late	33	F	Intellectual Disability
11	Corey	Site 2 Late	18	M	Autism Spectrum

Table 2: Overview of each of the clients participating in the observational sessions. Participants are listed by site and order of entry into the program.

Coach ID	Gender	Disability Experience	Training
Site 1 Coach 1	M	1	In person, Zoom and Videos
Site 2 Coach 1	F	5+	Zoom and Videos
Site 2 Coach 2	F	5+	Zoom and Videos
Site 3 Coach 1	M	5+	Zoom and Videos
Site 3 Coach 2	F	5+	In Person and Videos

Table 3: Overview of the DSO coaches site, gender, experience in the disability sector and training method.

4.3.1 Ongoing communication with coaches. For the duration of the program the coaches were in email contact with the education manager and research team. The DSO coaches have their own chat groups they form when delivering the same sessions to share best practices and inspire each other with ideas, activities, and their client's work. This documentation was done through photos and videos of activities that were also shared with us. They were also able to ask questions via email and request more materials if required. This communication channel allowed us to establish the amount of experience each group had with the toolkits, the duration of the sessions, the sorts of activities that were taking place and allowed us to plan our site visits.

4.3.2 Contextual inquiry and recording. The researchers attended each site to video record some of the sessions and observe and speak to participants and coaches. The experience of each group at the time of each observation is shown in Table 3. Video capture was performed using a fixed camera on a tripod to capture the room, a 360 degree camera to capture the table where most activities were performed, and smartphones to capture the clients' work on specific projects.

4.3.3 Reflective interviews with coaches. Finally, we ran semi-structured interviews with the coaches after conducting analysis of the sessions to present our analysis back to them and solicit their views on our findings. This gave them an opportunity to comment on the accuracy of our assessments and provide additional information about similar phenomena they had observed in other sessions. We also used this as an opportunity to discuss their reflections on using the STEAM package, their personal experiences running the sessions, and thoughts on how the package might be improved.

4.3.4 Analysis. To analyze the corpus of data, we followed a thematic analysis approach [10] looking for themes consistent across the groups or marked contrasts between them. We interrogated these themes to understand which could be explained by the amount of time spent with the STEAM package or the character of the groups. We drew inspiration from methods used in research with groups of students living with disabilities [61], so our work presents vignettes from the video that illustrate the core themes augmented with thoughts from the coaches given in the semi-structured interviews conducted after 6 months and 12 months with the package.

Unlike other research on teaching STEAM related skills, we could not apply a test to the clients in the DSO groups to assess changes in their abilities. We agreed with the DSO coaches this would be affected by the clients verbal ability. Moreover, it lacks a baseline and risks discouraging clients from engaging with the STEAM package, which could ultimately be distressing for them. We used a method based on other work with children living with disabilities [28] that used creative exploration of music to introduce concepts, without explicit instruction and minimal structure except play. Their evaluation was undertaken through play rather than testing including conversation, observation and progress notes. In addition, in line with other computing education research [4, 34], we developed a set of characteristics of problem solving and followed the DSO's approach with other educational sessions of assessing the session to look for examples of the behavior ourselves. The characteristics we looked for were:

(1) *Identification of a problem or goal and setting an intent to address it*: We looked for activities addressing specific challenges rather than emerging through happenstance. They reflect deliberate processes of reasoning rather than random interactions with the toolkits that happen to address a problem. This "problem formulation" is one of the practices considered essential by computing education researchers [34]. For example, a smiling face is drawn by a bots path on purpose rather than random movements happening to resemble one.
(2) *Iteration and step-by-step problem solving*: Problems are broken into sub-problems and solved one after another, allowing for simplification and partial successes to build on. Incremental problem solving has been shown in children as an adaptive process that consists of "iterative cycles imagining and building - developing a little bit, then trying it out, and then developing further" [11]. For example, TapeBlock kits that do not work are fixed with a series of diagnostic steps first looking for surfaces that are not in contact, then looking for surfaces that should be in contact etc.
(3) *Automated, abstract instructions*: Clients use controllers or buttons to give abstract instructions that can be replayed to solve problems and observe the outcomes. Prior work in this area has shown that abstract programming patterns are learned by students when they create games to model scientific phenomena [4]. For example, programming a desired movement using the Sphero toolkit's ability to follow a drawing of a path on a phone screen to move themselves to a target.

Broadly speaking, these characteristics are representative of active participation in problem solving and helped us focus on deliberate rather than accidental actions and results.

5 FINDINGS

Our analysis of the sessions and discussions with the coaches revealed three major themes: that physicality enabled diverse experiences, created real-world analogues, and supported group interactions; the group's played a role in supporting attention, motivating each other, and allowing space for coping mechanisms; and growing confidence in problem solving and the emergence of self-directed activities. We discuss these alongside the key qualities of the toolkits that influenced them, highlighting what worked easily and where we encountered more challenge. Before we present these findings, we briefly contextualize the sessions by describing the different sites.

5.1 The Sites

Each site had a distinct character. The coaches created and adapted the activities based on the needs and interests of their client groups. However, as time progressed and the clients became familiar with the STEAM package, they initiated their own projects. Site 1's coach was the most familiar with electronics and had participated in the STEAM program for longest. The sessions we were present for were characterized by focus with one client leading the conversation and two clients attentive and engaged but using infrequent, single word utterances. Site 2 was energetic bordering on chaotic as clients engaged, disengaged to recharge, then enthusiastically re-engaged with the activities. Two clients engaged in conversation while one used single word utterances and one was non-verbal relying on gestures to communicate. Site 3 was characterized by complete engrossment in the activities and technical capacity - the two clients had exceptional focus and completed an enormous number of activities. They only communicated through gesture and body language meaning the site was very quiet and calm. The coaches had a responsibility to ensure that all clients participated and Site 2 was particularly challenging for them because it was the most energetic. At Sites 1 and 2, some clients moved their toolkits onto the floor (Figure 2a) because the tables were not big enough for large projects that involved laying out roads and building houses. For other clients in wheelchairs, the move to work on the floor was not possible but they instead made use of the extra space on the table to lay out their own work (Figure 2b), or used a remote connection to control a Sphero (Figure 2c), or watched solutions that were being deployed by others in the group.

5.2 Physicality enabling integration, mimicry and diverse interactions

The physical nature of the toolkits allowed several phenomena to emerge which would not have been seen if clients were learning programming in front of a computer terminal. Clients could watch each other at a distance, collaborate on problems, and the toolkits could interact with each other by physically being pushed into each other allowing the clients to engage in a wide range of activities.

5.2.1 Physicality allowing toolkits to integrate into other games.

Because the toolkits were physical items designed for *simple interoperability* (section 3.2.2), we observed the clients using them as part of other physical games or activities they already understood. The clients' existing knowledge appeared to provide a scaffolding for the new technologies, for example, Site 1 and Site 2 used the Bots with pens attached to make drawings of emojis, flowers, and smiling faces (Figure 3a). The coach reported clients at Site 1 enjoyed playing bowling prior to the sessions and were able to make a bowling game of their own out of TapeBlocks and Spheros, stacking the TapeBlocks and then using a phone to program the Sphero to drive into them and knock them over. This matched with our own observations showing that early on using them, the clients had discovered the toolkits were able to interact with one another physically. At Site 2, during observation sessions, the TapeBlocks were used to build roads and different settings that the other kits were able to navigate (Figure 2a). We saw images and observed sessions that showed that the physicality also allowed participants to appropriate other items to include in play with the toolkits. Cardboard, foam sheets, wobbly eyes and pipe cleaners were used to make characters (Figure 3b) and, at Site 3, the coach relayed how, in previous weeks, the participants had found cardboard tubes that they raced their Spheros down (Figure 3c). The physicality of the toolkits also helped enhance other interactions such as when learning how to use them, Coach 1 at Site 2 noted that *"because it's so hands on, the STEAM program, the clients love engaging with it a lot more because they can create things."* Coach 1 at Site 1 also saw the same benefit, noting that when it came to learning, physical

(a) Roads made on the floor with TapeBlock buildings alongside them.

(b) A Bee bot being programmed using it's button interface on a tabletop.

(c) A Sphero placed on the ground being controlled from the table.

Figure 2: Moving to the floor or to the table to meet client needs for different devices.

examples created *"more visual references"* showing how to do things and helping the clients enormously.

5.2.2 Physicality allowing mimicking of real-world experiences. The physicality of the toolkits meant that clients were able to make simulations of real-world scenarios with them and they frequently did so, beginning the process of *building towards personal meaning.* We observed a wide range of different simulations of the real world being made such as a road-traffic simulator that fed into an ambulance simulation for traffic accidents at Site 2. At Site 3, in previous weeks the participants had gone for a walk in the community and their coach encouraged them to look for things they wanted to make in the STEAM session: *"Do you want to make a car puppet, or birds? And so then they came up with insects. So grasshopper, because they saw it."* They chose insects and showed us the grasshoppers and ants they had made–these were converted into puppets to be placed over a Sphero allowing them to run around the room (Figure 3b).

The activities that were modeling the real-world were often tied to particular *"special interests"*—as Coach 1 at Site 2 phrased it—the clients held. For example, at Site 2 we saw Noah (C4) replicate traffic on a track and other clients joined in crossing the "road" they had formed. Then an accident took place and an "ambulance" unit was sent out to take a pedestrian to the hospital. Coach 1 at Site 2 relayed to us that the client was fascinated with emergency services. All the participants at Site 2 had also gotten involved in making a re-creation of the city they lived in previously, going as far as planning (Figure 4a), reconstructing the city with TapeBlocks (Figure 4b) and selecting specific skyscrapers to build (Figure 4c).

5.2.3 Physicality allowing diverse group interactions. The physicality of the kits allowed the clients and coaches to help each other by

(a) A Bee Bot being programmed to draw a smiling face with a pen attachment.

(b) The Sphero insect puppets that were inspired by real-world observations.

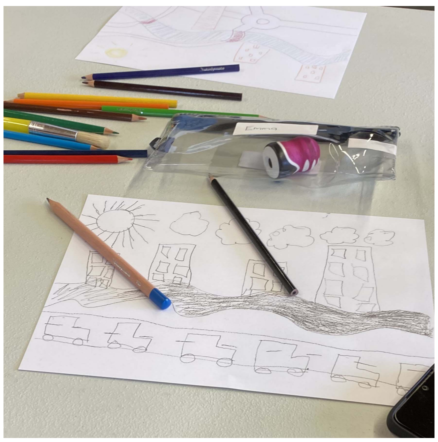
(c) Cardboard Tubes used to race the Spheros through.

Figure 3: The STEAM package enabled physical interactions in novel forms with provided and found materials.

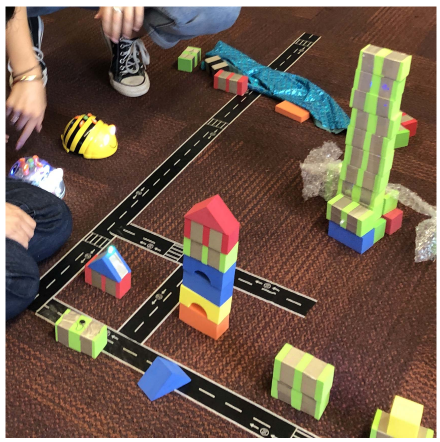
fetching things that were needed, sharing objects, and contributing to their organization. These simple collaborations were *language independent* and showed how *community activities* emerged. For example, at Site 3 Sahib (C8) was observed passing components to John (C9) (Figure 5a). The physicality supported sharing experiences between participants at a distance and engagement with the tools as well. We saw clients observing others as they worked without having to enter their personal space, allowing them to work un-distracted. We saw how Noah (C4) took a break from the session to pace and calm themselves walking around work areas while inspecting the layout of other toolkits showing one way a client could engage in their own *individual activity* without being totally disconnected from the rest of the group. This sort of disconnect or 'resetting' is commonplace amongst the DSO clients across all the activities they engaged in, not just STEAM toolkit sessions, and the physicality allowed them to walk away without totally disengaging.

At other times, the physicality of the toolkits supported different types of *community* activity when they allowed disruption between clients. We frequently saw one client knocking another toolkit out of alignment or, in one case, Noah (C4) pretending to trip over the toolkit and making an exaggeratedly slow fall to the floor while knocking the toolkit out of place. On video review, this incident happened because Noah (C4) had stepped into the personal space of Abdul (C5) who had gently poked them in the leg prompting their exaggerated fall. These incidents all appeared to take place in good humor - jokes between friends rather than an argument or fight.

The wheelchair using clients also benefited from this physicality as they observed the behavior of other clients at a distance, at Site 1 Mark (P3) would watch the work across the table intently but not



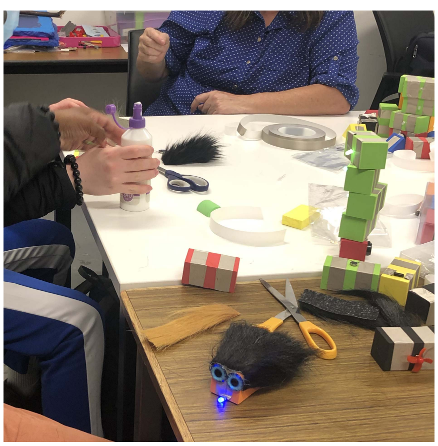
(a) A drawing of the city used to plan out the construction with TapeBlocks.



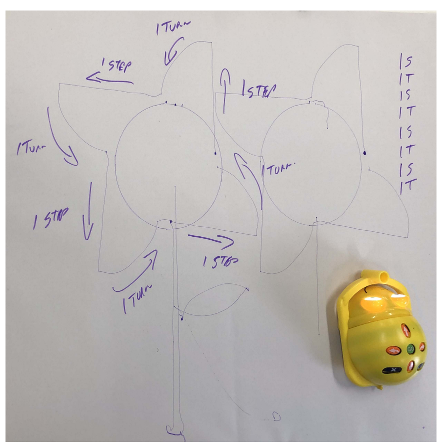
(b) The clients building their model TapeBlock City.

(c) A prominent tower which was replicated in the top right of image (b).

Figure 4: The planning and making of the local city with TapeBlocks



(a) The clients sharing components with each other.



(b) Bee Bot Flower instruction set written down by a coach guided by Mary (C3)

(c) The Rugged Bot which was brought to Mark (C3) by Mary (C2).

Figure 5: The sharing of physical objects lead to sharing, encouragement and motivating each other

take part himself unless directly approached by the coach. His engagement with the problems they were taking on was clear though as, at several points, he cheered for the success of Kayleigh (C1) and Mary (C2) before they had realized they had been successful, for example, realizing the program they entered into a Blue Bot was going to draw out a flower on paper (Figure 5b).

5.3 Individual needs met through group dynamics

We created the STEAM package with the goal of *supporting community and individual activities* but the interactions we observed were more nuanced than we had expected. Each client had their own support needs in the sessions, some needing help with physical aspects of the work, some needing techniques to help them maintain focus, and others needing cognitive stimulation or social support and affirmation. We observed numerous instances of clients helping, cheering, stimulating, and playing pranks on each other.

5.3.1 Focus and frustration. The clients exhibited different degrees of focus and engaged with the toolkits in different ways. Some clients worked with the toolkits in short bursts of 2-5 minutes before becoming distracted for a few minutes before reengaging, taking time to socialise with other clients or talk with coaches, while other clients worked in almost total silence and focus for an entire 2 hour session. We frequently observed prolonged periods of focus on other clients work as well, for example, at Site 1, Kayleigh and Mark (C1 and C3) watched Mary (C2) work in total silence for almost 20 minutes and at Site 3 participants maintained focus on the tasks for over 90 minutes without a break. Some of this we attributed to the *diversified repetition* that was possible with the toolkit, but the coaches also made clear in interviews that this was often the preferred way of working for some clients where made possible by the activity anyway.

In contrast with the obvious focus, the absence of frustration with the work was also noteworthy for the coaches who talked with us about the problems that they usually face when delivering other sessions (e.g., sessions they typically conduct with their clients) and how rare it was to experience those issues with the STEAM package. We did observe numerous instances of failures that the clients persevered to overcome, for example, a Blue Bot unit not connecting to the Bluetooth tactile reader at Site 1 which Kayleigh (C1) tried to solve for almost 40 minutes, or at Site 2 a TapeBlock tower that Abdul (C5) built kept falling over for 26 minutes until it was secured (Figure 4b). The absence of outcome driven pressure and the proper tempo of work, enabled participants to persist and overcome problems without becoming overly frustrated. Coach 1 at Site 2 summarized this saying *"the amount that goes into the program for each week is a good amount, we seem to get through it but it's not too-much or not-enough."* Reflecting after a year with the toolkit, Coach 2 at Site 3 told us that they had not seen disengagement but they did add that the skill of the coaches who took it upon themselves to learn to use the package was also a part of this - knowing how to pace sessions and when to drop it to avoid a negative experience were fundamental skills coaches developed a feel for. Coach 2 at Site 2 had even started to work the package into their own sessions with the clients - they had started to run a set of up-cycling craft activities that reused discarded items to make models and sculptures. The clients they worked with and the coach were starting to use the STEAM kits to spin wheels or light up the artworks.

5.3.2 Coping mechanisms and distraction. We observed several coping mechanisms that the clients were able to engage in to maintain or reset their focus. The most common behavior was for a client to remove themselves from the group work and go to another part of the room for a while as others worked. During our observations, sometimes a coach would check in with them such as in the case of Kayleigh (C1), but others would be left to their own devices like Lalya (C7). Noah (C4) liked to pace to relax, walking in circles or back and forth, but we noted when he did this in our sessions that he also liked to look at the projects that others were working on. We also noted this observation of the work while removed from it with Kayleigh (C1) as well. Other clients employed their own pacing of activities to manage frustrations or sustain attention. At Site 1, Mary (C2) worked rapidly, moving from topic to topic while talking constantly, whereas Mark(C3) was content to intently watch others work for almost 40 minutes, take a break and briefly nap, then come back and start to engage with the technology. Other clients seemed to enter a state of flow with the work - Sahib (C8) and John (C9) worked for 90 minutes without any distraction or break in both our sessions observing them.

Humor also played an important role in coping with moments that could otherwise have caused frustration for many participants at Site 1 and Site 2 though not at Site 3. At Site 1, a Bee Bot drawing on the table instead of paper caused Mary (C2) to put her head in her hands but the other clients and coach laughed about it and she then joined in. A Bee Bot falling off the table was almost always met with cheers and laughter at Site 1 and Site 2. Sometimes the clients did distract each other from the work as a way to cope with their own loss of focus. In some cases they talked to someone else, particularly for Leigh (C6), but in many others they engaged in playful mischief and pranks. Noah's (C4) deliberate fall was one example of this, but we also saw the almost totally non-verbal Kayleigh (C1), when told to be careful where she drove her Blue Bot, immediately drive it into one of the researchers with a grin on her face causing everyone to laugh. We also saw her send a Sphero racing across the table at Mark (C3) which both of them seemed to find incredibly amusing. These types of incidents reinforced that although the participants were non verbal they were able to communicate and engage effectively with the group.

5.3.3 Motivation through shared ideas and encouragement. Encouragement was given between clients at Site 1, Site 2 and at the more reserved Site 3 as well with many examples of the clients cheering the success of their friends. We also saw other examples of support though, for example, during an observation session Mary (P2) grabbed a Rugged bot and ran it over to Mark (C3) saying *"Mark's the expert on this!"* (Figure 5c). We also saw examples of the work that clients had done inspiring each other. Site 1 was the first group to commence the program, they created a video that was shown at an inter-site event, this inspired other clients to enroll in the STEAM program as they were excited by the work of others. At Site 1 a client created a Father Christmas character with TapeBlocks that moved around the table using a vibration motor (see Figure

6c). Other clients were inspired by the artifact and built either a Father Christmas or an elf based on the design.

5.4 Emerging problem solving approaches and personalization

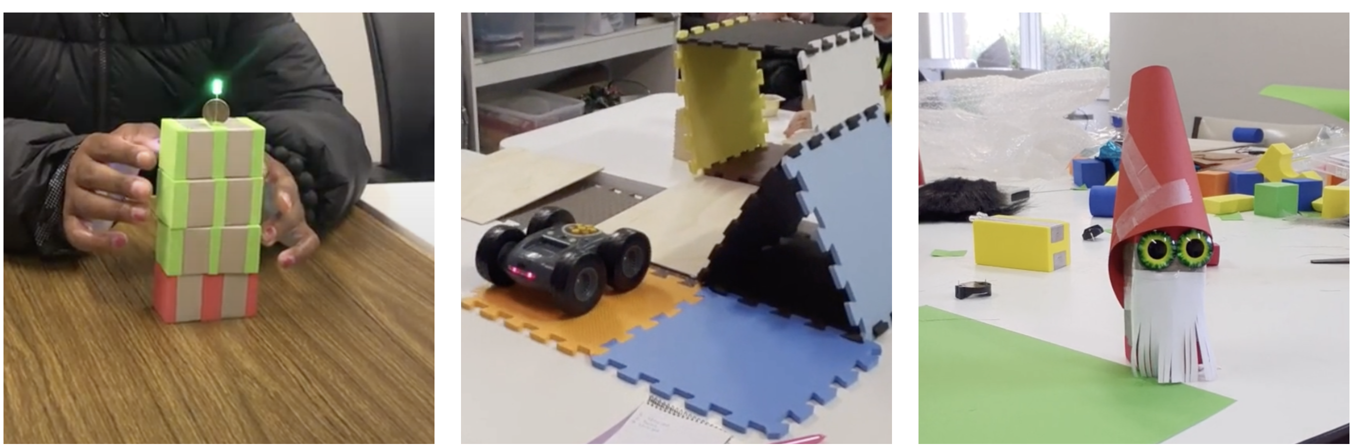
We were able to observe multiple examples of clients identifying very specific goals for their work, like clients at Site 3 aiming to make a model of insects (grasshopper and ant) that moved around (Figure 3b), Site 2 clients trying to replicate the city they lived in (Figure 4b), or Site 1 setting out to draw an emoji with spiky hair. Clients were able to select specific toolkits to try to implement their ideas and, in one case, even made a plan on paper of what they wanted the results of the work to look like (Figure 4a). We saw multiple examples of sequential programming to solve a problem as well, with Mary (C2) coming up with the steps to draw a flower, asking a coach to record the steps on a whiteboard and drawing a flower with the Bee Bot (see Figure 5b). We also observed many cases of clients failing at a task the first time they tried but then iterating on it to address it. Coach 1 at Site 2 commented on the persistence when learning to use Spheros, *"even the control of using a device and also going through different things you can do on that device ... When we first introduced them, they weren't interested in using them to do the joystick yet. Now they've done that, they want to use different skills"*.

We also saw these skills applied to smaller technical problems clients encountered and solved. For example, Kayleigh (C1) tried to help us work through problems with a Blue Bot's Bluetooth connection and John (C9) was able to work through the issues with building a roof LED TapeBlock (see Figure 7a) that they were making from components when it would not light up. John (C9) started by trying to press down the conductive tape to check that the connection was secure, they then checked that the tape had a gap so that there were no short circuits and then they turned the roof around to check the direction (polarity) of the circuit. When the light worked, they celebrated this with the group by cheering and clapping. Coach 1 at Site 2 commented on these phenomena saying *"I think visually Mmm, it's amazing for them to see their work sitting in front of them and then have an outcome which is fun."*

5.4.1 Confidence leading to creativity and autonomy. As participants worked through the process they became more comfortable with the technology and, even in single sessions, we saw them move from following instructions from coaches to selecting from choices offered by the coaches to proposing their own ideas and projects. Prior to our sessions, coaches sent us images of creative projects that the clients had done that included time lapse light-paintings using the Spheros and paintings that made use of stencils with the Spheros (both seen in Figure 7b & 7c).

Increasing confidence with the tools also led to more self-directed work with them as well. At Site 3, we observed Sahib (C8) making a light at the top of a tower of TapeBlocks (Figure 6a), while at Site 1 Mary (C2) led the group in building a ramp that they could send the rugged bot up and through a tunnel (Figure 6b). At Site 2, Leigh (C6) decided to build trees for the city that the group had built and used TapeBlocks in combination with bubble-wrap to make LED illuminated trees to line a street with (Figure 4b). Lalya (C7) realized she could attach a bulldozer blade to the front of her Bee Bot and used it to move her TapeBlock around without prior experience or prompting. Coach 1 at Site 3 commented on the independence saying, *"So what I'd be telling future people would be to give them more time and give them more independence."* In sessions that ran prior to our visits, the coaches also reported clients making Father Christmas characters with TapeBlocks which the clients designed to move around the table by having a vibration motor included in them (see Figure 6c). The other clients were inspired by the artifact and built one for themselves rather than being taught about it by researchers or coaches. They then worked out how to incorporate the design into the characters they were building.

Reflecting on the whole process, Coach 1 at Site 2 told us *"because it's so hands on, the STEAM program, the clients love engaging with it a lot more because they can create things and they're so creative and its like trying to figure out how to piece it all together or how to*



(a) A light on top of a tower made with the TapeBlocks.

(b) One example of a Ruggedbot tunnel, another was made from found cardboard.

(c) The vibrating Santa Character which 'walked' when switched on.

Figure 6: Self directed ideas that were created after building knowledge

(a) **Trouble shooting a loose TapeBlock circuit connection step-by-step.** (b) **A Sphero stencil painting made by Site 1 for the STEAM program.** (c) **The Sphero light drawing made using long-exposure photography.**

Figure 7: Successful problem solving to create circuits and using the Sphero for various creative activities

build things and then the smiles on their faces when they figure out how it all works is just amazing."

5.4.2 Accessibility through personalisation. We observed that small issues in regards to *manual dexterity* and manipulation of the toolkits had enormous effects. For example, at one stage the project switched the type of polyvinyl acetate (PVA) glue it was including and the new brand didn't adhere to the TapeBlocks and other kit as well as the previous brand causing several clients to be unable to use the TapeBlocks. Some clients also found the conductive tape used in TapeBlocks kits was *"too springy"* jumping into shape too quickly or too hard to peel the back off. These were the most significant barriers to accessibility and reinforce the importance of attention to small details when designing toolkits.

At the same time, the coaches and the clients were also able to solve many of the barriers they encountered without any help from the research team. One client at Site 2 who used a wheelchair, struggled with the use of the smartphone to control Spheros because she was placing it on her wheelchair tray and trying to drive the Sphero but ended up pushing the phone off the tray. Double sided tape from the toolkit was used to fasten the phone to her tray temporarily and she was then easily able to drive the Sphero. We also saw a variety of solutions to the conductive tape problem, ranging from a technique to only cut the conductive tape and not the masking strip of tape to coaches pre-cutting lengths of tape for clients and attaching them to the edge of the table. Finally, barriers that we had not anticipated were also addressed by clients and coaches. At Site 1, Mark (C3) was able to clearly drive his rugged bot over a lengthy course despite being in a wheelchair because the other clients put cardboard between two tables to form a large, navigable area.

5.4.3 Growth over time. There was a distinct progression in the confidence of the clients and the coaches over the course of using the packages that strongly tied to how personal the end results of the work were to them. We saw clear differences between observations after 20, 80, 120 and 200 hours with Site 1 (see Table 1) and, to a lesser extent, between 30 and 130 hours with Site 2. Observing groups at their first session with the devices we saw that the clients were initially unsure of how to use the kits but would become more engaged when the coach suggested building something they liked. One coach reported, for example, having them use the Sphero to play football because it was the start of the football season. Coach 2 at Site 2 and Coach 2 at Site 3 both reported seeing growth in the confidence of their clients working with the devices for up to three months, but at Site 1, with 200 hours experience, the clients had reached the point of making their own entirely self-driven projects that held obvious *personal meaning*. We observed Kayleigh (C1) making their own wedding out of TapeBlocks in the final observation session, sitting down and trying to build a dozen characters with TapeBlocks representing the priest, husband, and groom. She told us that this was because she was going to attend a wedding next week and the coach told us she was fascinated by the wedding, talking about it in several prior sessions. In the same session, Mark (C3) had decided that they wanted to make gifts for their family and was using other equipment in the space outside of the package to burn their names into wooden coasters the coach had cut out for them. A fourth client had just joined the group since our last observation and was also on her third session, she was being helped by the three more experienced members.

6 DISCUSSION

Our work with the clients, coaches, and the DSO is ongoing and still changing in light of our findings. In this discussion, we reflect on how our work fits with other literature in this area while we reflect on how to approach the creation of the package and toolkits we use, how important an unhurried approach is in this experience driven teaching of STEAM concepts, and pragmatic and methodological challenges that arise as we try to grow our relationship with the DSO.

6.1 Package and Toolkits

Our fundamental finding that the physicality or embodiment is useful mirrors other research. For example, the Magic Cube intervention has been shown to help young adults with special educational needs to learn some computational skills through the development of a physical toolkit [36]. Tangible electronics have also demonstrated their value in helping other excluded groups and promoting group effort when teaching electronics skills to older adults using MaKey MaKey toolkits [51] and people living with dementia co-creating with e-textiles [62]. The TapeBlocks we used, another tangible electronics toolkit, have also been used to conduct remote work with young adults with intellectual disabilities during the COVID19 pandemic but there the physicality created challenges because of the remote nature of the work [21]. Despite this growing body of work, we still need to understand how we should start to formalize observations and assessment of these interventions, how to keep improving the design of the toolkits, and, more generally, how to configure sessions to support creativity without prescribing the form it should take.

The critical importance of good ergonomics we found, with sessions disrupted by small mistakes like using the wrong PVA glue, is similar to findings of Hollinworth et al. who reported that littleBits needed modification in order to be used with people with learning disabilities [27]. Lechlet et al. also found sharing of success similar to our own work among the students they worked with. However, they found that disruption or disengagement was a problem [36] where, in sharp contrast, we found it acted as a coping mechanism that allowed sustained focus. The personality of the groups, their classroom setting, and the older age of our clients might explain this difference but it may also be the longer time-frame of our work reduced the pressure of disruptions and changed their character.

The STEAM package and the toolkits within it were either developed specifically for the audience that used them or modified and re-framed for that audience with educational videos and activity suggestions. We cautiously note that there is an overlap between what worked with the young adults at the DSO and tools that are designed to be accessible for children [32, 66]– some techniques can help people with different abilities but crudely transplanting those techniques or tools is patronizing and ineffective. Instead, our approach should be finding the overlap in specific technical challenges that are addressed, for example, tangible programming concepts used with young children can be repurposed because they allow people to program without being able to read and write [65, 66]. With this approach, findings from work with older adults, people living with dementia and people with physical disabilities inspired our approaches. For example, helping to maintain focus and re-orient clients to tasks that persisted between sessions using tangibility [38].

6.2 Timescale and ability when working with people with intellectual disabilities

One of the key takeaways from this work is the importance of allowing clients to spend hundreds of hours working with toolkits rather than the tens of hours which is more common [21, 36, 53]. Over the course of a year and hundreds of hours of regular engagement with the toolkits, clients developed far more skills and directed the activities much more than any of the research team or the coaches had expected. One year into the process at Site 1, they are still finding new ways to employ the toolkits, new projects to take on, and showing continued improvement in their skills with the kits. Despite being of similar levels of support needs, the extra 70 hours Site 1 has had also shows in their confidence with the tools in comparison to Site 2 as well. Comparing how our findings fit with other literature that touches on electronics for people with intellectual disabilities, we find that Buehler et al. is one of the only cases to explore how skills change over extended periods, their work showing how 3D printing technology can promote engagement in special education settings including working at a similar site to our own for a year [14]. They found software controlling 3D printers created challenges, which supports our finding that physicality was a critical component of accessibility.

Bircain et al. worked over a two year timescale in a co-design project with adults with severe intellectual disabilities but report quite different findings on engagement [8]. Our sessions were between 2 and 5 hours long and this extended time with the toolkits seemed important to the clients because it allowed them to become familiar with them and work towards complex creations. The length of the sessions does necessitate that the clients are able to take time away from the work to relax but, unlike other similar work [36], we frequently observed them coming back re-energized in the sessions we were at and we found great value in this extended period of engagement where other works recommend much lighter touches over less time [8]. This may be due to the differences that arise from designing rather than teaching. We observed across the sites an ebb and flow to the intensity of the sessions as well that emerged naturally under the coaches guidance. In addition, it was important to understand the client's pace – the skilled coaches knew when to sit back and let a client struggle with a problem for up to 40 minutes, but for the research team, this was challenging because of a natural desire to help. However, by the end of this, we saw the clients eventually solve some of these problems and draw great satisfaction from their achievements. Here the work of Buehler et al. is most similar and they reported that 45 minute sessions with children were insufficient to cover everything and develop skills in this time frame [14].

6.3 Pragmatic and methodological challenges for researchers

We encountered a wide range of different pragmatic and methodological challenges in our work that we believe other researchers can benefit from understanding before considering taking on a long term project like this. While the heart of this issue is a strong relationship with the DSO, how you build that and the costs in researcher time and in data gathered were not immediately obvious to us at the outset of this project.

6.3.1 Building a lasting relationship with DSO and coaches. A good relationship and alignment with the host organization, the coaches, and the clients was critical to the success of this work. We created this relationship by letting them come to us with problems and taking a collaborative approach. This allowed us to build trust with every part of the organization showing that we took time for them, listened to them, and prioritized offering help with problems where our expertise could address them, over collecting data to create publications. Sharing or working within the philosophy of the host organization also helps produce this alignment, adopting some of their practices as other work in co-design has [8]. In our case, this came in the form of a shared goal of providing broad, rich experiences for their clients similar to "low floors and high ceilings" in other disability work [44] and adopting the organizations working practices like assessing programs through observational assessment of clients rather than testing [35].

Coaches in particular are skilled professionals and have extensive insights into their clients experiences and the ability to adapt things to suit their clients because of the volume of work they do with them. When collaborating with them or creating the STEAM package to support them, we tried to recognize their skills and creativity and avoid being prescriptive by giving them flexible tools to adapt as they saw fit. We provided a starting point and taught some of the skills needed to let coaches and clients create. This approach paid off as Coach 2 at Site 2 was building their own program of activities that focused on up-cycling – turning rubbish into art – and they incorporated the STEAM package into their work. This coach's creativity can also be seen in our findings when, for example, coaches motivated clients by sending them into the real world to seek inspiration and their clients made replicas of what they saw, or when a coach introduced their clients to light painting and the clients worked out the patterns and Sphero controls.

6.3.2 Pragmatic barriers to extended deployments. While the benefits of the long-term relationship we have with the DSO are vital, other researchers attempting to recreate this should also be aware of the numerous barriers that have to be overcome to enable it as well. The most significant of these is coach training and retention. When coaches in the DSO are successful, they are often moved into more senior roles and there is relatively high staff turnover as well. This means that, over the course of a year, to deliver at the 3 sites we needed to train 7 coaches in the use of the STEAM package. Coach training and building their confidence with the electronics kits is relatively easy to do when we have access to the coaches, but responding to rapid changes in staffing isn't always possible and, at Site 2 for example, several temporary coaches were in place and left before they could receive any training with the STEAM kits.

The sessions themselves are also relatively chaotic and present methodological challenges for observational work. Sessions sometimes change location and are run by temporary staff frequently. In addition, some participants join and leave sessions midway through a program. While we collect consent forms from them, they might not stay in a session long enough to talk with us or they might be present in one session and not back for any subsequent ones.

Finally, managing and maintaining the equipment that we leave at the sites is also problematic. Batteries lose power over time, chargers are lost and parts of kits are misplaced or broken. We attempted to keep a link to simple online training material with each toolkit so, in the event an inexperienced coach used the kit, they could at least go online and follow a video but these guides were also lost or thrown away. Practically speaking well designed cases would incorporate the chargers so that they can't be taken away and build the instructions to access the website material into the case so it can't be lost.

6.3.3 Limitations and Wider Methodological challenges. There are several limitations on the generalisability of our study that should be considered when interpreting it's findings. First, the DSO we worked with was a supportive, professional, large service with many clients and might not be representative of the 'typical' DSO, in fact, we would argue there probably is no 'typical' DSO given how they need to respond to cultural, situational, temporal, and legal factors. In an ideal world, we would have also liked to engage in co-design with the DSO clients as well as staff designing the intervention we deployed. More observations over a longer period of time might also unveil significant differences in the development of groups or find a 'ceiling' for engagement with the project as well. If we could have developed an assessment tool for this work and the learning from it, a larger group would have helped to validate some of our findings.

Our focus on developing packages that were deployed with clients primarily without researcher intervention was important but challenging. Conventional research methods that compel a researcher to be present all the time collecting data are not the right fit for this environment [37, 59, 61]. The presence of a researcher in related medical cases is particularly disruptive [40] and the Hawthorne or observer effect seemed to be pronounced in this work, putting pressure on clients to perform and coaches to interfere sooner to achieve more. While there are successful studies performed in educational settings [50] and there is even best-practice guidance for interviewing people with mild intellectual disabilities [54], the more pervasive and serious nature of the learning disabilities the clients we worked with have, meant we were not confident we could employ those methods. Observations also places a particularly technically skilled helper in the room and risks creating an inauthentic view of the toolkits that are used while reducing trial and error learning.

This all combines to create a pressure to change the patient nature of the experience. Methods that allow a researcher to embed themselves in the teaching occasionally and then reflect on it such as ethnography or the sampling method that we adopted make more sense. However, the sampling only allows for snapshots of the process and not total documentation. We argue this is still valuable because the sessions frequently repeat themes and so do each of the activities. The approach is also supported with other material from the coaches captured naturally as they discuss the program with each other and validated through reflective interviews with them.

7 CONCLUSION

The more sessions we ran, the more obvious it became that the work reported here was one part of a much longer conversation with the clients, coaches and the DSO organization. Working for up to a year gave us insights into the experiences of the clients with the STEAM package we made, their support needs, and their creativity but it did not come close to finishing the journey the clients started developing their skills and expressing their creativity. The organization of the process and the design of the resources we provided in the STEAM package can also be improved and expanded. The work remains ongoing and we anticipate it shall remain this way for years to come. The goal of this project is to achieve client enrichment and engagement and not necessarily education and assessment. Learning and skill development are just one part of this for the clients. Their shared experiences of successes and failures, companionship, the artworks they made and their creations were all just as important to them as the things they learned. This research demonstrates the capacity of this user group to build skills, increase independence and drive personally meaningful electronic projects given adequate time.

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