Designing a Customizable Picture-Based Augmented Reality Application For Therapists and Educational Professionals Working in Autistic Contexts

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ABSTRACT

This paper presents the design and evaluation of CustomAR – a customizable Augmented Reality (AR) application, designed in collaboration with therapists, that allows them to create and customize picture-based AR experiences for use in an autistic context. Using a 2-week diary study, we gauge whether the application's customization options and features are sufficient to allow therapists and educational professionals to create AR experiences for the various learning activities they conduct with autistic children, and what challenges they face in this regard. We find that participants think the application would be suitable for creating AR experiences for a wide range of learning activities, such as choice-making and teaching daily living skills, and think that the application's freeze feature can be helpful when working with children with limited attention. Towards the end of the paper we discuss the challenges users face when trying to incorporate picture-based AR in practical therapy exercises, and how they can be addressed.

CCS CONCEPTS

• **Human-centered computing → Mixed / augmented reality**; **User studies**; • **Social and professional topics → People with disabilities**.

KEYWORDS

Augmented Reality; Picture-Based; Marker-Based; Autism Spectrum Condition; Education; Therapy; Customization;

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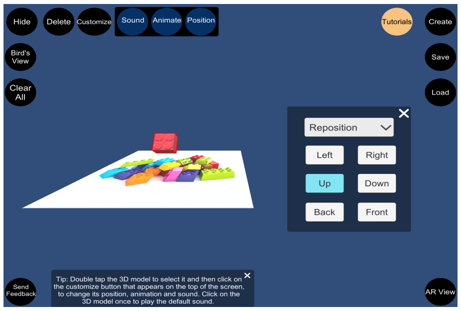
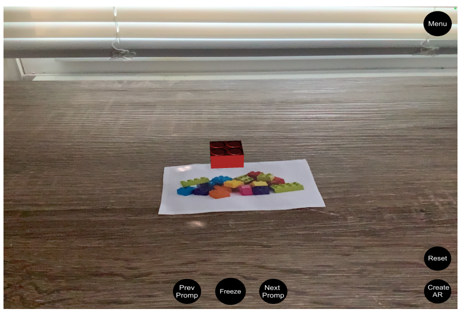
1 INTRODUCTION

Autism Spectrum Condition (ASC) is a neurodevelopmental condition that is often characterized by difficulty in communication,



(a) The CustomAR Application. The figure shows the creation window. Users can associate audio, videos, or 3D models with a target image to create an AR experience. The white plane to the center-left of the screen shows the image the user has uploaded. The user has added a Lego block 3D model to this AR experience and is customizing its position.



(b) The AR-View window. Users can view their AR experience by going to the AR-View window. The user has printed the target image onto a piece of paper, and is holding up their device camera to the target image to elicit the associated AR experience. The 3D Lego block has appeared on their screen.

Figure 1

social-emotional reciprocity, and repetitive behavior [34]. Autistic children[1] often have varied learning and behavioral profiles – some may have more difficulty with expressive and/or receptive language, others may have difficulty understanding and regulating emotions and behaviors, and many demonstrate very specific interests [34, 52].

While there is no one-size fits all approach to teaching, therapists and teachers on an autistic child's support team often adopt learning strategies that utilize *visual supports* (pictures, icons, photographs etc.), as they have been shown to be effective in autistic contexts [50, 56]. Picture-based Augmented Reality (AR) is a logical extension to learning activities that rely on visual supports as it allows pictures to be superimposed with additional information or virtual content (audio, videos, 3D models etc.) - the virtual content appears on the screen when the picture comes into view of the user's device camera. Augmented Reality, in general, has shown to increase focus and engagement in children with autism [30] and Picture-based AR, in particular, has helped autistic individuals complete daily living tasks more independently [22] and has helped them improve their communication [40] and emotion recognition skills [19].

However, practical use of these previously designed AR applications may be limited in therapeutic or learning environments because they lack support for *customization*. Therapists and educational professionals often need to customize learning exercises and content according to an autistic child's interests [37, 41], to keep them engaged and encourage positive behaviors [16, 57]. Customization is key, and the lack of support for customization could make it difficult for therapists and educational professionals to integrate picture-based AR into the day-to-day learning activities they conduct. Therefore, there is a gap between *research into* AR applications and the *practical use of* those applications, and a scarcity of work that bridges this gap.

Therapists and educational professionals are also key players in the adoption of assistive or learning technology. Prior to introducing new technology into an autistic child's educational plan, they must use their clinical and educational experience to evaluate the technology and determine how to effectively utilize it in an intervention [27]. Therefore, to design AR applications that are useful in practical autistic contexts, it is important for the research community to understand the customization needs of therapists and educational professionals, how they envision using AR in the learning activities they conduct with autistic children, and what features will be most useful in this regard.

Our contribution is as follows; We first highlight the design and implementation of CustomAR; a mobile AR application, created in collaboration with therapists, that allows them to create and customize picture-based AR experiences from scratch (refer to figure 1). We highlight key lessons from each of the two phases of the design process - from engaging in *participatory design* with therapists to create the first version of the application for a specific symbolic development use-case, to modifying the application into a customizable authoring tool. The latter could potentially allow therapists and educational professionals to create AR experiences for a variety of learning contexts, and for a diverse population of autistic children.

Secondly, we conduct a 2-week diary study and follow-up semi-structured interviews with special education teachers, occupational therapists, and speech language pathologists, to gauge whether they think the application's customization options and other features are suitable for use in autism-related learning contexts. Moreover, we shed light on the challenges that could hamper the use of picture-based AR in practical therapeutic or educational settings. Our study reveals the following:

- Therapists/teachers find the application's customization options sufficient to create AR experiences for a myriad of learning activities, ranging from choice-making and teaching daily living skills, to teaching lessons on emotion recognition and for collaboration and group-work. Details of these learning activities and the customization options that supported their development are provided in section 6.2 and 6.3.
- Therapists/teachers appreciate the ability to 'freeze' AR experiences on the screen and think that it would be useful when

[1] A note on language: Adolescent and adult self-advocates in our studies and our advisory board have shared that they strongly prefer identity-first language (e.g., autistic person) [15, 46]

working with children with limited focus, or when showing AR experiences to children in groups. This is discussed further in section 6.4.
- Therapists/teachers are concerned about generalizing AR experiences or creating them 'just-in-time' during therapy sessions (section 6.5). Allowing users to share AR experiences with others, and recommending AR content to users may alleviate these concerns. This is discussed further in sections 7 and 9.1 respectively.

Our work provides valuable insight into the features and customization options that will help therapists and educational professionals introduce AR into the learning activities they conduct. Although autistic individuals did not take part in this study, our findings may be useful for future studies that position autistic children as content creators and investigate which features/UI are suitable to allow them to independently create AR experiences. In the subsequent sections of this paper, we summarize related work, provide details about the two-phased design process and the user study, present and discuss our qualitative findings, and highlight limitations and future directions for this research.

2 RELATED WORK

This section leverages prior work to highlight how therapists and educational professionals use visual supports in learning exercises, how picture-based AR can extend them, and the significance of customization and interest-based learning in autistic contexts.

2.1 Using Visual Supports in Learning Exercises & How Picture-Based AR Can Extend Them

Therapists and teachers frequently use visual supports, such as pictures, symbols or photographs in learning activities involving autistic children as they often exhibit strong visual processing abilities [50]. For example, teachers or therapists may tape pictures that represent the day's activities (visual schedules) to the walls of a classroom to make it easier for autistic children to transition from one activity to another [5, 25]. Similarly, they may print pictures depicting the steps involved in a daily living task, and tape them somewhere in the environment as reminders [1, 50]. Visual supports are also used during choice-making activities, reinforcer assessment activities, or activities involving speech and language [3]

Picture-based AR is a logical extension to some of these learning activities that rely on pictures/symbols, and can add layers of information and helpful hints on top of them. When users hold their devices over a picture to elicit the associated AR content, the *context of the activity* (the picture/photograph, the tabletop etc.) is preserved, and users can view *additional information* without shifting their focus away from the task at hand. For example, Cihak et al. took a traditional tooth-brushing exercise in which a picture of the steps in the task was taped to the bathroom mirror, and superimposed the picture with a video clip depicting how each step was performed. Autistic children accessed this additional information by holding their device cameras up to the picture and could replicate the steps using the toothbrush, toothpaste, and paper cups in front of them. The study found that autistic children performed the tooth-brushing task more independently when AR was used [22]. Prior studies have also used picture-based AR to enhance the learning effects of social stories, [20], to teach emotion recognition [17, 19], and to improve children's communication abilities by reinforcing the meaning of pictures/symbols found in the Picture Exchange Communication System (PECS) [40, 47]. Picture-based AR, therefore, can be an effective teaching tool in an autistic context and as such it is important to understand what tools and features could facilitate therapists and teachers in using picture-based AR during the learning exercises they conduct.

2.2 Autism, Interest-Based Learning & Customizable AR

Studies have shown that customizing learning exercises according to the unique learning needs and interests of autistic children [33, 35] leads to positive behaviors [16, 28, 57]. The ability to customize, therefore, may be invaluable to therapists and educational professionals working with autistic individuals. However, a recent survey study revealed that current computer-based technologies designed for autistic individuals lack robust support for customization [44]. This includes studies under the umbrella of 'augmented and virtual reality' - although AR interventions have shown to support autistic individuals in various domains [38, 39, 45] including communication [40, 58, 59], daily-living [22], pretend play [12, 13, 26], and social and emotional learning [29, 43, 54], research into *customizable AR* is lacking [44].

Very few studies have provided users with the ability to customize picture-based AR experiences [24, 47], and even then users can only customize within the confines of an activity, e.g., being able to change the virtual content associated with predefined PECS symbols, but being unable to create an experience around new symbols [47]. Moreover, there is only one AR application on the Google play store (for android devices) that allows users to create their own picture-based AR experiences [2], and this application has not been created with the needs of therapists/teachers and autistic children in mind.

In contrast, we involved therapists in the design process and drew on their clinical experience in working with autistic children. Subsequently, we created an application that not only gives them the agency to create and customize picture-based AR experiences from scratch using their own images and virtual content, for learning activities that they themselves have conceptualized, but that also contains features that could potentially facilitate the use of AR in autistic contexts. Moreover, we investigate the practical challenges they could encounter when trying to inculcate picture-based AR in autism-related learning activities - something that no prior work has looked into thus far.

3 RESEARCH GOALS & HIGHER LEVEL RESEARCH QUESTIONS

Our first goal is to provide therapists and educational professionals with an application that allows them to create and customize picture-based AR experiences from scratch. Section 4 describes the two design phases that culminated in the development of our customizable AR application.

Our second goal is to evaluate this application by conducting user studies with therapists and educational professionals. We aim to understand; (1) whether therapists can sufficiently use the application's creation and customization features to create AR experiences for their autistic students; (2) whether the freeze feature – a feature that was developed based on feedback from therapists during the design phase (section 4.2.3), and which allows them to freeze AR experiences on the screen while keeping the experiences interactive – is useful in the context of autism; (3) what challenges therapists face when trying to integrate picture-based AR in the learning activities they conduct.

The specific research questions (RQ) are listed below:

- **RQ 1: Are the application's customization options sufficient to allow therapists/educational professionals to create AR experiences to meet the varied interests and learning needs of the autistic population they work with?**
- **RQ 2: How does the application's freeze feature facilitate the use of AR in the context of autism?**
- **RQ 3: What are the challenges in using picture-based AR in practical therapy/learning settings?**

Section 5 highlights the results of the user study we conducted to answer these research questions.

4 APPLICATION DESIGN

We designed and developed our application in two phases. In phase I (section 4.2), we designed the application in collaboration with 4 researchers/Speech Language Pathologists (SLPs) from the Boston Children's Hospital's outpatient clinic in Waltham, Massachusetts. The goal was to use AR to enhance the symbolic knowledge for the moderate to severely autistic children that visited the clinic. Our collaborating SLPs informally tested the application and realized that the lack of customization options was hindering its use. We then re-designed the application in phase II (section 4.3), to allow users to create/customize picture-based AR experiences for a variety of learning contexts and autistic individuals, not just those specific to the clinic. In this section, we highlight our design journey; We describe our initial symbolic development use-case, features of the first prototype, and the lessons we learnt that spurred the redesign of the application into a more customizable tool. We then describe the features of the latest version of the application.

4.1 The Design Team & Participatory Design Process

Our multi-disciplinary design team comprised of computer scientists and 4 researchers/SLPs from the Boston Children's Hospital's outpatient clinic in Waltham, Massachusetts. These clinicians primarily work with minimally verbal children with moderate to severe autism and provide diagnostic, and speech and language evaluations and treatments. At the time of introduction the SLPs were exploring AR in play contexts, but had no prior experience with picture-based AR.

The design process was as follows; the first author visited the clinic weekly for a month, and then bi-weekly over the next 3 months for design meetings. The first month was dedicated to outlining the features of the application, and the content of the AR experiences (e.g., the target images and 3D models used, the audio and animations to create for each model etc.). Over the remaining months, the first author coded the application's features and UI. When a feature was coded, the first author would demonstrate the feature during the bi-weekly in-person meetings. The SLPs would provide feedback and suggestions for improvement or redesign, and modifications would be made accordingly. The SLPs also informally tested the application amongst themselves (at the end of Phase I) and provided feedback that spurred the redesign of the application into a more cutomizable tool (Phase II).

4.2 Phase I - Designing an AR Application for a Specific Clinical Context

4.2.1 ***Symbolic Development Use-case:*** In phase I, the goal was to design an application that could enhance symbolic knowledge for the minimally verbal children with moderate to severe autism, that visited the clinic. The SLPs often centered therapy around play, and these children were familiar with numerous toys present at the clinic.

Let's consider a common scenario at the clinic; Sam is a 7 year old male who regularly visits the clinic. He has moderate-severe autism and very little functional speech (a few intelligible spoken words). Therapists at the clinic want to teach Sam how to requests for objects (toys, food etc) by pointing towards pictures of those objects, instead of trying to grab the objects themselves, physically dragging an adult towards where the objects are being kept, or showing disruptive behavior. When the therapist presents Sam with two objects that he likes, a toy (a Lego block) and a snack (goldfish crackers), he consciously points towards the object he wants. The therapist then puts the objects out of sight, and presents Sam with a *picture* of the Lego block and goldfish crackers instead. Sam is unable to point towards the picture of the object he wants. He does not understand that the 2D pictures are *symbols* that represent the 3D objects.

Since pictures and symbols are key to numerous alternate communication strategies [14, 31, 32, 49], it is important for these children to understand the symbolic relationship between 2D pictures and their 3D referents. In our example, Sam does not have a clear understanding of this relationship. We hypothesized that if we could momentarily convert the 2D into 3D, that is, superimpose the 2D pictures of the objects with highly similar 3D models of the objects, Sam may understand the 2D-3D symbolic relationship and be able to make a conscious choice between the available options.

4.2.2 ***Content & Features of the Application:***

Basic AR Experiences: *The fist version of the application was very simple. We pre-programmed a few images and corresponding 3D models into the application (details present in the next bullet point). Therapists would open the application on an iPad and hold the device camera over a print-out of one of the pre-programmed images. The associated 3D models would then appear on the screen. Figure 2 shows a picture of Lego blocks and goldfish crackers superimposed with 3D models of the same objects. Names of the objects would appear on small banners beside the 3D models. When the 3D models were tapped, an audio recording of the object's name would play out. It is important to note that these AR experiences were built into the*

(a) Target image of Lego block and Goldfish crackers

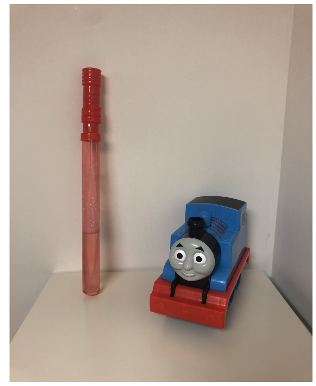
(b) 3D models of the Lego block and goldfish crackers appearing over the target image

Figure 2: Basic AR Experience

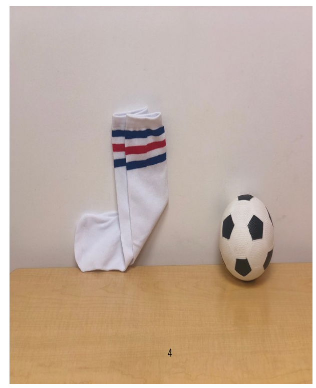
application. The therapists could not alter the target images or the 3D models associated with them.

3D Objects and Target Images: *The initial application was designed while keeping in mind the objects (e.g., toys) that the children at the clinic interacted with the most. The design team picked 6 objects - a bubble wand, a 'Thomas the train' toy, a large Lego block, a packet of goldfish crackers, a soccer ball and a pair of socks. Since the children were prompted to make a choice between 2 objects at a time, we took images of pairs of objects. These served as the 2D images the children would be presented with and the target images that the application would recognize. Examples of different pairs are shown in Figure 3.*

Animations: *Based on discussions with the therapists, we created an animation for each 3D model to promote engagement. For example, bubbles would appear in front of the bubble wand, the Lego blocks would start stacking on top of each other, and a few pieces of goldfish crackers would appear outside their packet. (Figure 4a). Each animation was paired with relevant audio, such as a popping sound for the bubble wand, a stacking sound for the Lego blocks and the sound of a packet opening for the goldfish crackers.*



(a) Bubble wand and 'Thomas'



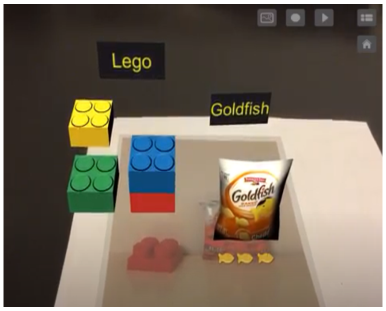
(b) Socks and soccer ball

Figure 3: Target Images

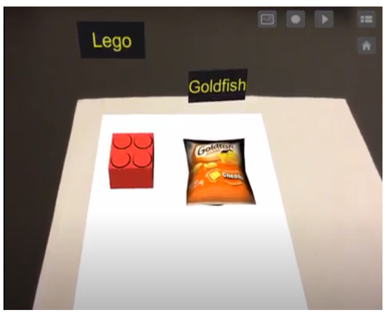
Hiding Target Images: *Sometimes when 3D models were superimposed over target images, there would be too many elements on the screen. Some individuals on the spectrum could perceive this as visual clutter or sensory overload [21]. To minimize this, we added a 'hide' feature to the application. A white plane would appear over the target image (Figure 4b), temporarily hiding the target image and drawing focus to the 3D models on top.*

4.2.3 ***Informal Testing & Design Considerations Moving Forward:*** Our collaborating SLPs informally tested the application amongst themselves and provided feedback. They were given a hi-fidelity prototype of the application and instructed to trigger the various in-built AR experiences, try out the animations for each 3D model, and comment on the strengths and weaknesses of the application. After using the application for several months, and due to the overnight shift to remote learning practices due to the Covid-19 pandemic [53], the SLPs faced various challenges. These challenges, and their implications on application design, are outlined below.

Predefined Content and Varied Interests - The Need for Customization Options: *We tried to ensure that the target images and 3D models found within the application were representative of (and highly similar to) the objects found at the clinic that were interesting to the clinic's autistic population. However, the move to*



(a) Animations - Lego blocks stack and goldfish crackers appear



(b) Target image hidden by creating a white plane over the image

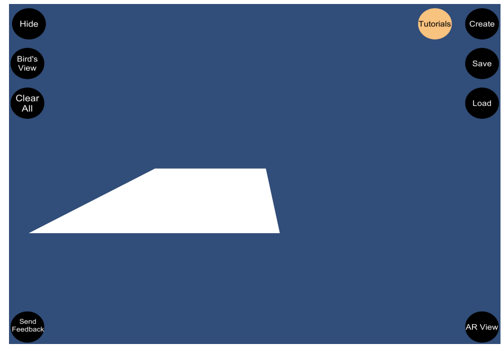
Figure 4: Animations and 'Hide target Image' Feature

online therapy due to the Covid-19 pandemic presented a challenge. If a child did not have these specific objects at home or did not find them interesting, the application would not be engaging/useful for them [41]. This feedback made it clear that our AR application had to be more customizable, in order to be usable outside the clinic and to cater to children's diverse interests.

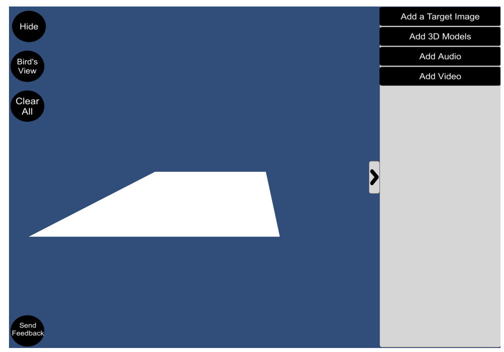
Dynamic Therapy Environments and Children's Limited Focus - The Need to Freeze Content: *Owing to the nature of AR technology, the AR experience is only visible on the screen when the device camera has the target image in its sight. However, constantly holding the iPad over the target image proved to be difficult for the SLPs, as therapy environments are dynamic; the child may be unable to sit at a table (and therefore near the target image) for long periods of time, or they may get distracted by another item in the room and wander off. The therapist may have to abandon the iPad to follow after the child and may find it difficult to make the child sit still long enough to trigger the AR experience again. We therefore needed to 'freeze' the AR experience on the screen, that is, retain the AR experience on the screen even after the target image was no longer in view of the device camera.*

4.3 Phase II - Re-designing the Application to Make it More Customizable

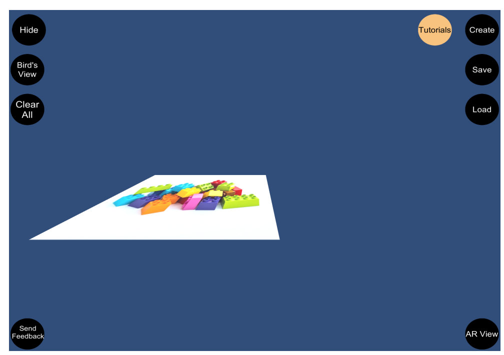
In Phase II of the design process, we added various customization options to the application to give therapists and educational professionals the ability to create and customize picture-based AR experiences according to the needs of the autistic population they work with. We also added the *freeze feature* to make it easier to view a completed AR experience. In this section, we provide details about these features and the UI of the application.



(a) Creation window



(b) Users can use the slide-in menu to add content to an AR experience



(c) The selected target image appears in the middle of the workspace

Figure 5

4.3.1 *Customization Options:*

Users can avail the following customization options:

- **Custom Target Images** - Users can select custom images to serve as targets for an AR experience by either taking an image in real time, or uploading an image from their device gallery. This gives each user the flexibility to create

AR experiences around the specific visual supports they use during learning/therapy exercises.

- **Audio Prompts** - Users can record an audio prompt for an AR experience. The audio prompt plays automatically when the target image is recognized by the application. Since users will decide on the contents of the audio recording themselves, they may choose to record short hints or longer, more detailed prompts, depending on the activity they have in mind.
- **Videos** - Users can associate videos with an AR experience by either recording them in real time, or uploading videos from their device gallery. We posit that this may be an important customization option as video modelling is widely used as an instructional method when working with autistic children [11, 23, 51].
- **3D Models & animations** - Users can add one or more 3D models to their AR experience from an in-built library of 3D models that contains 40 models spanning the categories of food, hygiene, toys, etc. Each model has a default audio prompt (the model's name) and at least one default animation associated with it. Users can record their own audio prompts for a model, and choose between animations if more than one is available for a particular model. Although we initially added 3D models because they were essential for the symbolic development use-case described in section 4.2.1, we were interested to know how users utilize them in other use-cases or learning activities.

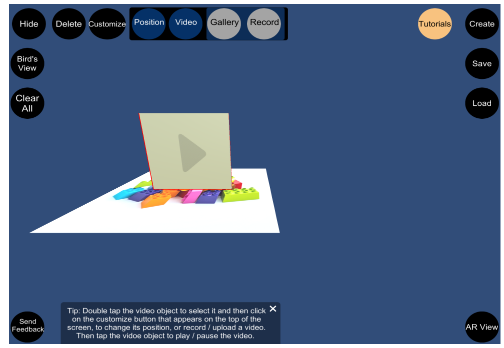
To simplify the process of creating and viewing an AR experience, we decoupled the creation and viewing windows. The customization options described above can be accessed through the creation window. The two windows are described below.

4.3.2 *Creation Window (Authoring Tool):*

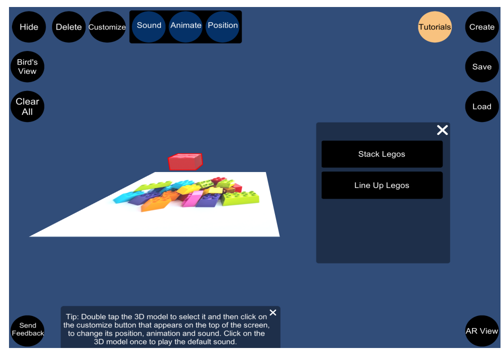
The creation window (Figure 5a) allows users to create their own picture-based AR experiences from scratch. The user must first upload a target image, which appears in the middle of the work-space (Figure 5c). Users can use the slide-in menu to add either audio, video, 3D models, or a combination of the three, to any AR experience (Figure 5b). The creation window shows what the target image and virtual content would look like if users were viewing them head-on, instead of from above. This is similar to how the AR experience will appear in the AR-view and helps users adjust the position of the virtual content in relation to the target image.

Miscellaneous options: *Users can change an animation associated with a 3D model (Figure 6b), and can re-position, resize, and rotate video objects or 3D models within their AR experience (Figure 6c). They can also clear the work-space, load/edit previously created AR experiences, and shift the camera to look at the work-space from above. Moreover, they can temporarily hide content that is present within their AR experience to facilitate adding and customizing more content. Users can also access video-based tutorials that explain how to create AR experiences and how to use all the miscellaneous features/options just described.*

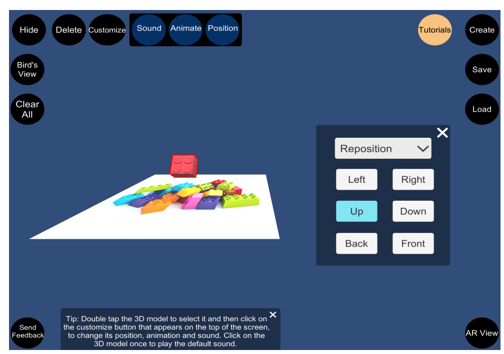
4.3.3 ***AR-View:*** The AR-View is where users can view their AR experiences by bringing their target images in front of their device cameras (Figure 7). This window contains features that facilitate the use of AR within therapeutic/learning contexts.



(a) Users can upload existing videos or take them in real time. Tapping on the video object (shown in the center of the screen), plays or pauses the video.



(b) Users can select one of the two animations (stacking or lining up the Lego blocks), using the animation window shown on the right.



(c) Users can re-position, re-size and rotate 3D models and videos, using the window on the right.

Figure 6

Freeze Feature: *The freeze button allows users to freeze the video background on the screen (Figure 7a), while keeping the AR content interactive. This allows them to retain the context of the AR experience (the video background and the target image), and move the device away from the target image without the AR experience disappearing. This could be useful in dynamic therapy/learning environments where* *a child is unable to stay near the tabletop. The therapist could activate the AR experience, freeze it, and then bring the iPad/device closer to the child for better viewing. Prior work has also shown the effectiveness of such a feature in mobile-AR contexts [42].*

Settings Menu & On-screen Buttons: *The settings menu allows users to change the speed of animations and the light intensity, hide target images and switch between 'sound mode' and 'animation mode' for the 3D models (Figure 7c). The latter determines what happens when a user taps a 3D model in an AR experience - either the associated audio or the chosen animation plays out. In situations where a user has added more than one type of content (audio, video, 3D models) to an AR experience, they can toggle through the content using the 'Next' and 'Prev' prompt buttons present on the bottom of the main screen (Figure 7a). By default, the 3D model appears first, then video, and then audio. Users can reverse this order using the settings menu.*

This version of the application, at the end of phase II, was used when conducting formal user studies with therapists and educational professionals (section 5). .

4.4 Implementation Details

The application was created using Unity [55] and C# scripting. We used the ARCore [8] and ARKit [36] XR plugins to provide the necessary AR functionality for both the android and iOS version of application respectively. We used the interface provided by AR Foundation [6], within Unity, to communicate with these two plugins. This allowed us to use the same code-base to build both an Android and an iOS version of the application.

5 USER STUDY

To answer our research questions (section 3), we conducted a user study that was approved by our university's Institutional Review Board. Recruitment was done over the course of five months, from June 2021 to October 2021. The details are as follows:

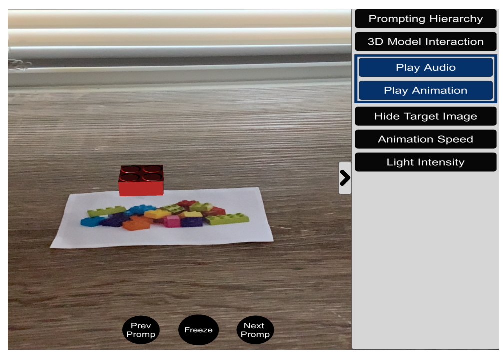
5.1 Participants

We recruited participants using word-of-mouth and snowball sampling. All our participants were therapists or educational professionals who had prior experience working with autistic individuals. We recruited a total of 10 participants in the study; 7 participants completed the study, 1 participant withdrew because she was not comfortable with downloading the application on her personal device, and 2 of them did not complete the study.

For simplicity, we refer to participants using ID numbers P1 to P7. P1 and P2 belonged to the same clinic as the SLPs that helped design the first version of the application (Phase I). However, these participants were not present during the design discussion in phase I and did not have access to the application prior to their enrollment in the study. Since the first version of the application was created for a specific use-case for the clinic, we wanted to see how the latest, more customizable version could be useful for the same use-case. Recruiting therapists who had negligible involvement in the design and creation of the application, but were familiar with the use-case, allowed us to get an unbiased opinion.

(a) The 3D Lego block is superimposed over the target image. The Freeze and Next and Prev prompt buttons are present at the bottom of the screen

(b) A video object superimposed over the target image



(c) The different settings options

Figure 7

Please note, no autistic children participated in this study. Our goal was to get feedback from therapists and educational professionals first and refine the application, before testing it with autistic children in future studies.

5.2 Study Method

Each participant was enrolled in a diary study spanning 2 weeks. Participants first took part in a one-on-one information session via Zoom [9], where they were introduced to the application and downloaded it on their preferred devices. They were instructed to use the application over the next 2 weeks to create their own AR experiences, and provide feedback about its strengths/weaknesses and what learning activity or contexts of use they had in mind. We built feedback options into the application to encourage participants to provide feedback. The types of feedback they provided are discussed in section 5.4.

At the end of their 2 weeks, participants took part in a one-on-one semi-structured interview with a member of the research team. This helped us get an in-depth understanding of how the participants used the application and in what contexts, what challenges they faced, and what improvements they would like to see. At the end of the interview, participants were asked to permanently delete the application from their devices.

5.3 Procedures

5.3.1 ***Information Session:*** In the information session, a member of the research team first explained what picture-based augmented reality was and then played demo/screen capture videos of the application to explain its layout and the features. Interested participants were taken through an informed consent process in the presence of a witness. The participants then downloaded the application on their preferred devices. All our participants used iOS devices. For iOS users, we distributed the application through Apple's Testflight [7].

5.3.2 ***Diary Study and Follow-up Interview:*** During the 2-week diary study, we sent emails twice a week to remind and encourage our participants to continue testing the application and provide feedback. At the end of the 2 weeks, we conducted a one-on-one interview with them via Zoom. These interviews typically lasted an hour and were either audio or audio/video recorded based on the participants' preferences (indicated in the consent forms).

5.4 Data Collection & Analysis

5.4.1 ***Types of Data Collected:*** We collected the following qualitative data:

- Written feedback - Participants provided written feedback by filling out a short Qualtrics survey [4] that opened up in a browser when they clicked the 'Survey' button in the application. This short survey asked participants to indicate which features they used, how they used them, and any other comments they had.
- Voice notes - Participants provided verbal feedback through the application by recording voice notes and pressing the 'Send Voice Note' button to upload them to an AWS simple storage bucket [10]. Similar to the survey, participants had to elaborate on which features they used, and in what contexts.
- Interview recordings - The audio/video recordings of interviews were manually transcribed. In the interviews, we asked our participants to describe their overall experience with the application, what AR experiences they created and for which learning exercises, what features may be more useful in autistic contexts etc.

5.4.2 ***Analysis Methods:*** We performed a thematic analysis on the written feedback, and the transcripts of the voice notes and interview recordings. Braun & Clarke's [18] approach to thematic analysis was used. A member of the research team first transcribed the data, generated initial codes, gathered data/quotes pertaining to each code, collated them into themes, discussed the themes with other members of the research team, and then reviewed and refined them. A second coder (from outside the initial study team) validated the themes and the data belonging to each particular theme.

6 RESULTS

We asked our participants to explore the application while keeping in mind the autistic population they work with, and the learning exercises they conduct. As such, some participants only explored features relevant to the context they were developing their AR experiences for, while others explored as many features as possible. In this section, we first highlight the participants' general experience/progress with the application and provide details about the learning activities they had in mind. We then analyze their feedback and interview responses to answer our research questions.

6.1 Participants' Progress With the Application

All our participants encountered a learning curve when testing the application, but some made more progress than others. These participants either got better after repeatedly using the application, were able to intuitively figure out what to do, or took advantage of the in-app tutorials.

6.1.1 ***Getting Better After Repeated Use:*** Some participants mentioned getting better at using the application over time. For example, P1 said that she was able to 'figure things out' after she 'played around with it' and that with repeated use, she would be 'more comfortable' with the application. Similarly, P2 got faster at using the application over time. She stated, 'I definitely got faster at it. And so once I was able to do it like a couple times, it was pretty seamless.'

6.1.2 ***Using One's Intuition:*** P5 mentioned that the initial tutorial in the one-on-one information session was enough for her to use the application 'independently', and she 'didn't really have to go back to the tutorials that are built in'. She thought the buttons 'were clear', 'made sense' and if she was not sure what to do then as an 'intuitive user of apps like this', she was able to 'figure it out'.

6.1.3 ***Leveraging the In-app Video Tutorials:*** P1 mentioned that the in-app tutorials were 'definitely helpful' and P7 said that they were 'great reminders'. P6 had trouble remembering what the miscellaneous buttons on the screen did (e.g. the 'load' button) and sought help from the in-app tutorials. She stated that she was not 'good at remembering steps' so she watched the tutorials multiple times, which were 'very clear and very easy to understand'.

Participants who made less progress either failed to notice the in-app video tutorials, or were unclear on how to trigger the AR experiences they had created.

6.1.4 ***Lack of Prior Experience With AR & Failure to Notice In-app Tutorials:*** P4 enjoyed 'exploring' the application, but was 'new to AR' and so 'had some difficulty' with creating full AR experiences and viewing them. She did not notice the 'tutorial' button in the application and was therefore unable to get help.

6.1.5 *Confusion About How to Trigger an AR Experience:*
P3 misunderstood how to trigger an AR experience and instead of using the target images to trigger the experience, she tried to use the actual objects she took images of. For example, instead of holding her camera to the picture of her driveway, she held it up to the actual driveway and had a hard time making sure the camera was in the 'right place' to trigger the experience. This negatively impacted her progress with the application. Similarly, P6's AR experiences did not appear on the screen because her target images were so big that the entire image was not in view of the device camera. We identified and corrected this issue during the interview, and she was able to trigger her AR experiences right then. That said, both participants provided feedback based on the features they successfully explored, and brainstormed improvements. Despite encountering issues, P6 'really liked' using the application and, at the end of the study, said that it was 'too bad' she could not have it again.

In section 7.3 we discuss some improvements we can make to help reduce the application's learning curve.

6.2 Details of Learning Activities

Our participants envisioned creating AR experiences for a range of learning activities. Table 1 provides background information about each participant, the features they explored, and what learning contexts they had in mind.

P1 and P2 considered the same symbolic development use-case that was described in section 4.2.1 – they wanted to help children make intentional choices using pictures of objects (toys, food etc.) by superimposing them with 3D models of the objects to strengthen the link between 2D images and their 3D referents. P3 wanted to use the application to give children situational cues – such as how to behave when entering a classroom. P3 and P4 both wanted to teach daily living skills, such as 'hair-brushing' or tooth-brushing' by using the application to superimpose pictures representing the steps of an activity with videos of the activity being performed. Children would trigger these videos when they forgot the steps in a task. P5 was confident that her high-school students could independently use the application during group-work to create an AR battle game using picture cards. Students would collaborate to make the rules of the game, would decide which pictures to use, and would associate actions with each picture (using audio or 3D models). Players could trigger these actions by holding their iPads over each picture. This spurred the discussion on whether any changes need to be made to the UI so that autistic children could create AR experiences on their own (section 7.4). P6's school used worksheets (called 'News2You') that paired action words, such as kicking, with pictures depicting the action. She wanted to superimpose these static pictures with videos showing what the actions looked like. Lastly, P7 envisioned using the application to give 'reminders or second prompts or visual cues' to children during group activities or if a paraprofessional was not nearby to repeat instructions. He also wanted to reinforce the visual schedules in his classroom with audio prompts. Children could then 'independently go up and check the schedule' by holding their iPads over the images in the schedule.

6.3 Participants' Experiences With The Various Customization Options

As mentioned in 6.2, our participants envisioned using the application for a plethora of learning activities, for autistic children ranging from younger kids with severe autism, to those who were independently navigating high-school. In this section, we discuss our participants' experiences with the application's customization options and answer **RQ 1**.

6.3.1 *Recording Custom Audio:*
Participants could record audio prompts that would either play automatically when a target image was recognized, or would play when the associated 3D model was tapped. P1 added the sound of a train honking from a Youtube clip to the 3D model of 'Thomas the train' for her choice-making activity and said that she could see 'a kid really enjoying it because it's so realistic'. P5 highlighted that children 'may be stimulated by having their voice recorded' and wanted her students to record audio prompts for actions associated with each card in their battle game. For example, a card could say, 'You lost five points'. P6 and P7 used videos for their primary use-cases (teaching language and creating reminders), but used audio for secondary activities. They imagined using audio to pair instructions for a math lesson, or sounds of musical instruments with worksheets and pictures respectively. Children could hold up their devices to the worksheets/pictures to listen to the instructions or the musical notes.

6.3.2 *Adding A Custom Video:*
Participants liked the option to add videos into the AR experience because videos either grasp a child's 'attention' better than 'static' content (P1) or because autistic individuals 'imitate video models more' than if a person performed the same action in front of them (P2). The latter especially could help with teaching daily living skills. P2 added a video of someone brushing their teeth, over an image of a tooth brush, to teach this daily living task and P6 imagined using videos to demonstrate the meaning of action words and emotions. For example, when conducting a lesson on frustration, she could superimpose an image of a frustrated kid with a video showing what 'frustration looks like'. P7's goal was to foster independence in the children he worked with - If stuck, they could hold their iPads up to their worksheets to trigger a video of P7 giving them instructions, such as 'please write three complete sentences'. While an audio prompt may have achieved the same purpose, it seemed the participants valued the visual nature of videos. Participants who had trouble using this feature (P4) or who found it irrelevant to their use-case (P5) also thought that it had 'potential'.

6.3.3 *Adding 3D Models:*
Some participants used 3D models as an integral part of their AR experience (e.g., P1 and P2 used the train, bubble wand, Lego block etc. for choice making activities), while others explored them out of curiosity (P3 to P7). P5 and P6 liked the ability to add multiple 3D models to an AR experience - P5 could then use different 3D models at the same time to demonstrate a theme, for example adding a coffee cup and toast together to represent 'breakfast', and P6 could add multiple 3D models to an AR experience for a math activity (e.g., 2 + 5). That said, participants agreed that having 'more options' (P1) or a 'broader range' (P2) of 3D models would be helpful. P2 worked with kids' in play contexts' and would have liked to see 3D models of other toys and P5 said

Table 1: Participants' Backgrounds

ID	Participant Occupation	Population in Mind	Learning Activity	Features Tested	Intended Users of the Application
P1	Speech Language Pathologist	Younger kids with moderate-severe autism who are minimally verbal	Choice making & symbolic development	Audio, Video, 3D models (a few) & animations, Freeze	The therapist holds the device and shows the screen to the child, the child may interact with the virtual content themselves or with the therapist's help
P2	Speech Language Pathologist	Younger kids with moderate-severe autism who are minimally verbal	Choice making & symbolic development, teaching daily living skills	Audio, Video, 3D models (a few) & animations, Freeze	Same as above
P3	Speech Language Pathologist	7th/8th graders with Autism who have articulation or significant communication difficulties	Teaching daily living skills	Video, 3D models (a few)	The therapist creates the AR experiences beforehand, and the kids use the AR-View to view and interact with the virtual content independently
P4	Special Education Teacher	High-school kids with moderate-severe Autism	Teaching daily living skills	3D models	—
P5	Speech Language Pathologist	High-school kids who are independently navigating a public school setting	Group work / collaborative learning, creating AR games together	Audio, Video, 3D models (a few) & animations, Freeze	The therapists or the kids independently create their own AR experiences and use the AR-view to show others what they have created
P6	Occupational Therapist	14 y/o with Down's syndrome & a child who suffered stroke in utero - kids who have difficulty speaking, low cognition and are emerging readers	Worksheets with action sentences, connecting words and language, teaching emotions, teaching math concepts	Audio, Video, 3D models (a few) & animations	The therapist creates the AR experiences, and the kids view them independently
P7	Special Education Teacher	autistic children in 4th grade	Giving children reminders or directions about individual or group-related class activities, visual schedules and pairing musical notes with images of musical instruments	Audio, Video and 3D models (a few)	The therapist creates the AR experiences, and the kids view them independently

that categories related to daily living, such as 'transportation' or 'morning routine', and for her use case, categories like 'battle ships' would be helpful. P7 typically puts clipart on his slides to show children what they need for an activity and could have done the same with AR if 3D models related to school supplies had been available in the in-app library, such as rulers, pencils, and crayons. Therefore, providing users with the ability to add 3D models themselves or search from a larger database of 3D models would be helpful. We discuss this more in section 6.5.1.

6.3.4 ***Using Animations****:* Some 3D models had simple animations, such as an apple rotating, while others had functional animations, such as a pair of hands getting soap from a soap dispenser. Participants found functional animations - animations that show the function of a particular 3D model – to be more useful. For example, if the toy train had an animation of the train gliding over, P1 could use it to teach concepts like 'pushing the train'. Similarly, P2 stated that the animations would be great for teaching 'choice-making', as they depict the function of the object. Although the 3D models of day-to-day objects, such as the toothpaste, had functional animations, P2 thought that having a sequence of animations that depict the item's use (such as all the steps involved in putting toothpaste onto a toothbrush) could be helpful in teaching daily living skills. Thus, while simple animations attract children's attention, functional animations are more useful from a teaching point of view. While animations may not be useful for every child - P3 stated that they would not be necessary for the 7th/8th graders she works with – they can be 'really important to have' when teaching children with severe autism, or to make the application useful for 'a wide variety of clients' (P3).

6.3.5 *Are The Given Customization Options Sufficient?*

Recall that **RQ1** considered whether the application's customization options were sufficient to create AR experiences for a range of autistic children and learning exercises. While participants suggested improvements for existing customization features, they did not find anything 'missing', and although participants were considering different learning activities, they were each able to find some customization options that were useful for their context. P6, for example, stated the following, 'I could definitely use the audio. I could definitely use video. I could definitely use an image. I can use all your features to teach a lesson on an emotion'. There is, however, a question of *how much customization is enough*? P5 thought the application provided a good balance of 'flexibility', without the 'possibilities being endless'. P5 envisioned a scenario where her students would create AR experiences themselves, instead of the teacher/therapist. To that end she stated that some previous tools she had used with her students (e.g., 3D printing software) had 'too many options', and students got 'bogged down in the details', were 'too frustrated', or 'working too independently without consulting each other', thus defeating the purpose of group exercises. Our application was simple enough that she envisioned her students 'running with it' and even 'coming up with something more creative' than her game idea, but without getting too bogged down. That said, a user may come up with a unique or niche use-case which requires more customization than what is currently available in the application. Future studies will need to investigate this. In the next subsection, we attempt to answer **RQ 2**.

6.4 Can the Freeze Features Facilitate the Use of AR in an Autistic Context?

Our second goal was to understand whether the freeze feature could facilitate the use of AR with autistic individuals. Participants liked the freeze feature because it removed the need to continuously hold the iPad/device over a target image to keep an AR experience interactive. P5 saw its utility in group settings - she could 'capture' the AR experience on the screen and then show it to children who were sitting further away from her in a group. She also thought that taking a screenshot of the frozen AR experience and putting it in a visual schedule would help prepare children for future activities involving the application. Moreover, it could be helpful in scenarios where children were unable to focus or stay still. P1 mentioned that 'attention is sometimes very impacted' for children on the spectrum, so they may 'wander the room' or 'walk away' when she tries to show them something on the iPad. The freeze feature would be 'useful' in these situations as she could trigger the AR experience, leave the target image on the desk, and go where the child is. P3 echoed this sentiment and said that having the AR experience not 'disappear once you move to a different spot' would be helpful.

Therefore, it seems that the freeze feature may be especially important to have when using AR in an autistic context. In contrast to the freeze feature, most participants skipped over the settings options in the AR-View or only tried a few options. When asked why they did so, some participants said that they either did not feel the need to edit the default settings, or they were not needed for the activity being considered. In the next subsection, we talk about some of the practical challenges that users may face when using picture-based AR in day-to-day settings (**RQ 3**).

6.5 Practical Challenges of Using AR in Therapy / Learning Settings

When thinking of using AR in day-to-day settings, our participants were concerned about being able to access a wide range of 3D models, being able to create AR experiences on-the-fly or 'just-in-time' and generalizing AR Experiences. We discuss these concerns below.

6.5.1 *Access to a Wider Range of 3D Models:*

As mentioned in section 6.3.3, most of our participants thought that having a larger library of 3D models at their disposal would help them create AR experiences for a wider audience. P3 thought that being able to add one's own 3D models would be helpful. For example, participants could search for and download 3D models from the internet. However, these models may not have sounds or animations built-in; we had to build the animation and sound associated with each model in the application's library. Moreover, other participants, may feel the same as P2 who stated that this study was her 'first time really exploring AR', and she was unaware that one could search for and download 3D models from the internet. Therefore, building a library of models into the application, or hosting one online that users can access from within the application, may be preferable. If users are unable to find a relevant 3D model, they could potentially make requests for 3D models and associated animations through the application, which would then be fulfilled by members of the research team.

6.5.2 *Creating AR Experience On-the-fly or Just-in-time:*

Preparing resources or creating exercise material according to each child's interests can be a difficult and time-consuming process. Being able to 'customize an AR experience on-the-fly' during a therapy session would make a 'huge difference' as it would reduce the 'prep time' participants have to put in *beforehand* (P1). P3 echoed this sentiment, stating that one must 'make things quickly' while working with some children, and that it currently requires a 'lot of planning' to create relevant AR experiences. Therefore, some degree of intelligence / automation may be helpful. For example, P2 thought that it would be helpful if the application could detect the contents of a target image and quickly provide options for appropriate 3D models and audio prompts that label the objects. This would allow therapists and educational professionals to quickly create AR experiences *during* a therapy session, based on what the child is interested in at that moment. In section 9.1 we present a prototype for 'just-in-time' content creation as a proof of concept.

6.5.3 *Generalizing AR Experiences:*

P3 pointed out that 'generalization is a big area of focus when working with people on the spectrum'. It involves learning a skill or concept and using it in any environment, not just the one in which it was taught. P3 thought it would be great if an AR experience could be generalized. For example, in the context of hand-washing, the application would recognize that a sink was present and would pull up the AR content (audio, hand-washing videos etc.) that she had previously associated with another sink. While she was focused more on recognizing

3D objects and using those as triggers for AR experiences instead of pictures, her idea could be extrapolated to work for pictures as well. Moreover, she thought that if a clinician could create an AR experience and share it so that 'parents can use it at home', it would help generalize the skills taught in school to a home setting. We discuss this further in section 7.

7 DISCUSSION

While users found the application's features and customization options to be useful, there is room for improvement. In this section, we use insights from our study to propose design implications for future applications (AR or otherwise) that target therapists and autistic contexts. We also discuss ways of reducing the application's learning curve and position autistic children as content creators.

7.1 Sharing AR Experiences & Just-in-Time Creation - Implications for Content Creation Apps

Sharing AR experiences was initially brought up in the context of generalization (6.5.3), but could also facilitate just-in-time content creation and collaboration/group-work. For example, therapists/teachers could share their AR experiences with parents, or vice versa, by uploading them to an online portal. This would allow children to be exposed to the same prompts/AR experiences in different environments, which could help with generalizing ideas/skills. Additionally, therapists could download and edit pre-made AR experiences or templates to speed up the creation process and reduce their own time and effort. Moreover, in class/group activities, teachers could upload a half-finished AR experience for their students to download and edit. Students could also share AR experiences with each other to collaborate or show what they have created so far. Therefore, applications (AR or otherwise) that involve content creation and target therapists/teachers and learning settings, should provide support for content-sharing and collaboration.

7.2 How Much Customization is Enough - Implications for Autism-Focused Customizable Applications

Recall that in section 6.3.5, we discussed whether or not our customization options were sufficient. Improvements to 3D models notwithstanding, perhaps one reason our approach to customization was successful was because we provided sufficient flexibility without the application becoming too overwhelming. For example, users only had the option of adding audio, video or 3D models but could decide themselves which of the three they wanted to add to an AR experience and what the *content* of the audio and/or videos should be. This allowed them to create AR experiences for a variety of learning contexts. Moreover, for future AR application that position autistic children as content creators, it might be helpful to provide a limited set of options but provide flexibility within those options, so that children can be creative without getting too 'bogged down' in the details. Of course some learning contexts may require support for a lot more customization, and by no means do we claim that our approach fits every context. However, as a starting point, future applications might consider providing flexibility within a limited set of customization options, or gradually introducing customization options to users. The latter is discussed in section 7.3 and 7.4.

7.3 Reducing the Application's Learning Curve - Tutorials & Gradually Exposing Functionality

Recall that some participants made more progress in using the application's features than others. Although we added in-app video tutorials, interactive tutorials where the application helps the user create and trigger their first AR experience and points out useful features, may further reduce the learning curve. P7 also advocated for gradually exposing the application's functionality to users. He stated that a lite version of the application, where users can only add audio to a target image, may be helpful for users who are not very technologically savvy. He stated that 'a broader range of people are more comfortable' with taking a photo or recording something, so limiting the customization options can help ease them into the creation process. Users can later upgrade to a version with videos and 3D models.

7.4 Autistic Children as Content Creators - Will Our Current UI Suffice?

We initially envisioned therapists and educational professionals as the main creators of AR experiences, while the autistic children they worked with would simply view the AR content. P5, however, stated that her high-school students could easily navigate the features of the application to create their own AR experiences. This begs the question: is the application's UI sufficient to allow autistic children to create their own AR experiences, or are modifications necessary? For example, some children may wish to hide some buttons on the screen to reduce visual input. Other children may have difficulty remembering the steps involved in creating an AR experience and may benefit from an interface that sequentially takes them through each step of the creation process. P7's idea of gradually exposing functionality to users, as mentioned in section 7.3, may be useful here as well; children can take their time and become comfortable with using one customization option before moving onto another. To make the application accessible to a wide range of content creators, we need to conduct user studies with autistic individuals, particularly those who can independently navigate similar applications and are interested in AR. We leave this for future work.

8 KEY TAKEAWAYS

The following bullet points summarize this work's key takeaways:

- The customization options we provided (audio, video and 3D models with animation) allowed therapists/educational professionals to create AR experiences for a variety of learning exercises. Participants appreciated our approach of providing flexibility within a limited set of customization options as it prevented users from getting too bogged down. Future researchers/designers creating applications in an AR and autistic domain may benefit from using this approach to customization (as a starting point).

- The freeze feature can be helpful when working with autistic students with limited attention, or when working in group settings. Future researchers/designers creating AR applications should consider providing a way to freeze AR experiences on the screen to make it easier to use with autistic children.
- Therapists and educational professionals may need to create content just-in-time during therapy sessions or may need to generalize the same content to different situations. Future researchers/designers who are developing content-creation applications for autistic contexts (AR or otherwise) should provide avenues for creating content quickly, or sharing content/AR experiences with others.

9 LIMITATIONS & FUTURE WORK

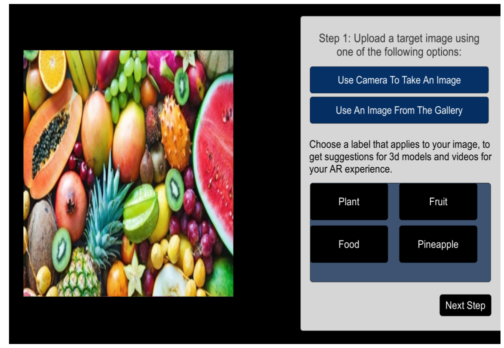
Our study had some limitations: Firstly, participants had a limited selection of 3D models. Future prototypes should allow users to upload their own 3D models, or provide a larger library to choose from. Secondly, we cannot make any claims about whether the application's current UI will be sufficient for autistic children to create their own AR experiences. We posit that a lite version, or a version that either gradually exposes functionality or systematically takes the user through each step of the creation process, might be helpful. That said, we have yet to conduct user studies with autistic children to confirm this hypothesis. The next subsection discusses a proof-of-concept prototype that could be used in future studies to answer some of these questions.

9.1 Just-In-Time Creation and Sequential Interface

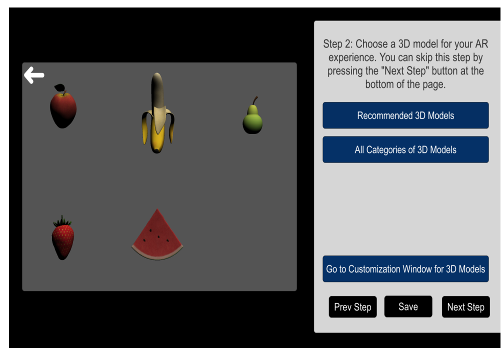
Based on the discussion in 6.5.2 and 7.4 about just-in-time content creation and the benefits of a sequential interface, we made some modifications to the application's UI. The third version of the application takes users through each step of the creation process sequentially. Users can move between steps using the buttons at the bottom of the screen (figure 8).

The application uses the AWS Rekognition [48] service to identify labels for the object, scene or actions present in a target image (figure 8a). Based on the label that a user selects, the application provides recommendations for 3D models (figure 8b). Users can still explore all the categories manually but we posit that providing them with some recommendations might speed up the creation process. Moreover, we use the AWS Simple Storage Service (S3) [10] to host a larger library of 3D models. Users can download these 3D models through their application. This allows us to provide a larger library of 3D models without encroaching on the user's device storage.

This third prototype is a small proof-of-concept. We hope to use it in future design meetings/studies with therapists, educational professionals, and autistic children to understand whether they prefer UIs where the customization options are exposed gradually/sequentially or all at once, and whether the recommendations given by the application are helpful when creating AR content.



(a) Sequential Interface. A user has uploaded a target image of fruits. The application used the AWS Rekognition service to provide the following labels for the contents of the image: 'Plant', 'Fruit', 'Food' etc. The labels appear in the window at the bottom-right and the user can select the most appropriate label.



(b) 3D Model Recommendations. The application has recommended several 3D models to the user based on the label they chose in the previous step ('Fruits'). The recommendations are shown in window on the left. The user can explore all the other categories of 3D models using the buttons at the top-right of the screen.

Figure 8

Other features, such as sharing AR experiences through an online portal, are more complex and require further thought.

10 CONCLUSIONS

This paper describes the design and evaluation of CustomAR, a mobile application that allows therapists to create picture-based AR experiences from scratch for use in autism-based learning exercises. A diary and interview study revealed that therapists found the application's customization options to be sufficient for creating AR experiences for a variety of learning exercises, ranging from choice-making activities to reminders, visual schedules and groupwork. We posit that our approach was successful because we provided a fair amount of flexibility, without inundating users with customization options. Participants also thought that the freeze feature would be useful when working with children with limited attention. Moreover, our study highlighted some challenges to using picture-based AR in practical therapy settings, such as finding

3D models that capture the children's interests, generalizing concepts, and creating AR experiences quickly during therapy sessions. Moving forward, application developers looking to create customizable applications for autistic contexts, should allow users to share their AR experiences or create experiences quickly – the latter may require incorporating some degree of automation or intelligence into the application.

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