Expressive mARks: Art in the Age of Augmented REality

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Expressive mARks:
Art in the Age of Augmented Reality

A Thesis
Submitted to the Faculty
in partial fulfillment of the requirements for the degree of

Master of Science
in
Computer Science with Concentration in Digital Arts

by Carson Levine

Guarini School of Graduate and Advanced Studies Dartmouth College
Hanover, New Hampshire

May 2023

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Abstract

Augmented reality (AR) and non-fungible tokens (NFTs) introduce new considerations for the long-standing debate of what it means for digital art to be “real.” However, the ability to create AR experiences is limited to those who are technically skilled or who can afford to consult someone else. This paper addresses the need for an accessible tool that enables artists of all technical backgrounds to expressively create marks in AR. The solution includes a mobile application called CrayonAR. The system was designed to be modular, minimal, and physically engaging, and was developed in Unity using ARFoundation and Firebase Storage and Realtime Database. Following preliminary feedback and iterations, we tested a working prototype of the app for general usability with 20 people of all technical and artistic backgrounds. The results demonstrated that despite small improvements that could be made to the user experience, the app successfully provokes curiosity and creativity from users, inspiring them to engage with familiar environments through novel visual exploration.
Acknowledgements

Thank you Lorie for being a Gardener of Delight.
Thank you Mahoney for teaching me that there are no rules, but there are consequences.
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Thank you to the faculty, students, and custodians of the Computer Science and Studio Art departments.
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1. Introduction

1.1 - Controversy of Digital Art

1.1.1 - Origins

In 1966, Bell Labs engineer Billy Klüver and artist Robert Rauschenberg embarked on an ambitious journey to bridge the gap between art and technology. [1] The Experiments in Art and Technology (E.A.T) collective brought research engineers together with visual artists, choreographers and composers in New York City. In October of 1966, the group staged *9 Evenings: Theater and Engineering*, a series of interdisciplinary performances featuring “many firsts for theatrical technology,” including television projections, dancers, fiber optic cameras, musicians, and sonar devices. Despite the involvement of many established artists—Steve Paxton, Robert Whitman, Alex Hay, Deborah Hay, David Tudor, Öyvind Fahlstrom, John Cage, Yvonne Rainer, Lucinda Childs, and Robert Rauschenberg—the performances stirred an uproar of controversy regarding its authenticity as a body of art. This response signifies a common pattern within the art world— a new concept of art emerges, contradicts tradition, solicits a harsh stamp of disapproval from critics, and then persists to redefine society’s expectations. We saw this in the rise of humanism during the Italian Renaissance, amidst the insensibility of Dadaism following World War I, and again with the non-representational gestural marks made popular by Abstract Expressionism. Ironically, the historical importance of an artwork is seemingly derived from its initial rejection by society-at-large. Nearly 60 years following Klüver and Rauschenberg’s disruption, it remains unsurprising that the ever-expansive involvement of technology in artwork continues to ignite contentious debate. [2]
German philosopher and cultural theorist Walter Benjamin notably addressed these drastic technological shifts in art during the early 20th century. In 1935, Benjamin published the first edition of his famous essay entitled “The Work of Art in the Age of Its Technological Reproducibility.” In it, he examines the impact of mechanical reproduction on the nature of art, arguing that it leads to a loss of the artwork’s unique presence in time and space. “What withers in the age of the technological reproducibility of the work of art,” fears Benjamin, “is the latter’s aura.”[3]

The aura is the soul of an artwork— its unique presence in time and space. “Based less on quality, use value, or worth per se than on its figurative distance from the beholder.” Though this “distance,” Benjamin contends, “is not primarily a space between painter and spectator” but rather that of the work’s “psychological unapproachability.” [3]

In a 2006 paper entitled “New Media and the Permanent Crisis of Aura” Boris Groys, a more contemporary prominent philosopher, art critic and media theorist, writes against digital disruption in our traditional understanding of aura. [4] Groys argues that by enabling the endless reproduction and dissemination of artworks, digital media strips artworks of their unique presence and authenticity. He reiterates some of Benjamin’s earlier concerns that “by replicating the work many times over, it substitutes a mass existence for a unique existence.” [3]

The introduction of NFTs to the digital art world begins to address some of these questions of uniqueness and authenticity. By minting a unique token on a blockchain, artists can create a verifiable digital certificate that authenticates the artwork and establishes its history
of ownership. [5][6] This helps prevent unauthorized copies and forgeries, which is particularly important in the digital realm, where replication is relatively easy.

Furthermore, at SIGGRAPH 2020, Liron Efrat presents a contradictory perspective to Groys. In his paper Efrat argues that artists can leverage the specific affordances of augmented reality to create meaningful and engaging experiences.

1.2 - AuRa

Augmented reality (AR) is a technology “in which 3D virtual objects are integrated into a 3D real environment in real time.”[7] AR exists within the domain of spatial computing, the “human interaction with a machine in which the machine retains and manipulates referents to real objects and spaces.”[8] Virtual reality (VR) is also spatial computing, though the computed spaces differ. In VR, the simulated space is an entirely new “world,” as the viewer is immersed within a completely virtual environment, typically via goggles. In AR, the computed space is the existing world around the viewer. The technology “augments” this reality by superimposing 3D digital graphics to appear within the space itself.

“By means of exposing actual environments as constructed and therefore as virtual landscapes,” Efrat writes, “mobile AR art exposes our situatedness and becomes a strong tool for activism as it encourages us to think beyond familiar, material reality.” [9] Efrat
emphasizes the significance of the “here and now” in AR art, which, according to Benjamin, “underlies the concept of authenticity… of the original.” [3]

Liron Efrat’s assertions echo that of Benjamin’s notable contemporary, Laszlo Moholy-Nagy— a Hungarian painter and photographer prominent in the Bauhaus movement. 98 years before Efrat’s SIGGRAPH paper, Moholy-Nagy published “Production Reproduction,” in which he discusses the relationship between technology, media, and the development of the human sensorium. He argues that new technology is “instrumental” to artistic development, “for art attempts to create new relationships between familiar and as yet unfamiliar data, optical, acoustic or whatever.”[10] Moholy-Nagy draws a distinction between production and reproduction: production is “any practice that employs technology to create new relationships” whereas reproduction is “the mimetic replication of an extant external reality.” Efrat would agree with Moholy-Nagy's belief that “extending the range and power of the human visual apparatus … can reveal to human cognition new relationships between elements of the perceptual world.” Benjamin would later call these “image worlds.”[10]

1.2.1 - Expansion of the Sign and Mark

In a 1917 essay entitled “On Painting, or Sign and Mark,” Benjamin introduces helpful terminology for the dissecting the aura of an artwork. Put simply, the “sign” refers to the deeper meaning within the work while the “mark” refers to the literal trace left by an artist. The “sphere of the sign,” he writes, “comprises diverse fields … characterized by the various meanings that the 'line' has within them.”[11] In painting, the primary focus of this essay, the artist’s “marks” are the physically existent components— the brushstrokes of paint— whereas the “sign” is the emotional meaning conveyed through their symbolism, shape,
color, form, and other visually expressed elements. As the context of art expands into the
digital realm, what does it mean to make an intangible mark?

The fundamental differences between digital and analog art are obvious and consequential.
In traditional painting, the mark exists as voluminous pigment rendered by a light source
reflecting off of the surface and received by our eyes, its “color” revealed. In digital creation,
the mark exists as a cluster of data– thermal memory– rendered by a computer through a
man-made light source (be it projection or screen display). In most digital art, the screen
and/or projection source contains the artwork. Even 3D digital art, in which objects have an
implied spatial volume, we still perceive the objects to be in their own universe. The
screen/projector acts as a window into this separate world, whose rules are self-defined.

Augmented reality blurs the boundaries between the digital world and our own. On mobile
devices, the phone’s camera captures the environment and the AR application processes the
image data and superimposes digital objects onto the surrounding environment. This
apparent non-existence while simultaneous feeling of presence prompts conscious and
unconscious questions of what is real during our experience. This inherent confusion of AR
allows artists to make uniquely ambiguous familiar marks.

1.2.2 - Contemporary ARt

Several prominent contemporary artists known for non-digital media have begun to
incorporate AR into their work, particularly following the COVID 19 pandemic.

As the world quarantined in May 2020, Olafur Eliason released an AR app called
“Wunderkammer,” an attempt to surround users anywhere with objects of wonder.[12, 13]
Weather has remained a core theme throughout Eliason’s career, and “Wunderkammer”
implies users to play with the “illusion of controlling the weather” through manipulation of delicate 3D animations created by the artist and his team at AcuteArt.

Later that year, Sarah Sze collaborated with digital agency Cher Ami to produce an AR app called “Night Vision 20/20” as a complement to her October 2020 show “Night into Day” at the Fondation Cartier pour l’art contemporain. Sze noted that it was especially important to her that she only venture into AR if the technology had something meaningful to offer, an inadvertent nod to the tension between sign and mark. [14] This particular endeavor sought to “offer the smartphone-enabled daytime garden visitors the chance to see the building at night, to overlay the nighttime display onto day. The phone could become “a sort of time machine, zooming you half a day forwards or backwards.”

Figure 1.2: Contemporary artists Olafur Eliasson and Sarah Sze created mobile AR apps in 2020.
1.3 - Considerations for an ARt Tool

1.3.1 - Limitations of ARt Software

Eliasson and Sze both worked with external teams to complete their respective AR projects, revealing the most notable limitation to a non-digital artist’s ability to experiment with augmented reality: the inaccessibility of its current technologies. Success of any artwork that incorporates technology heavily relies on an artist's technical knowledge or their ability to collaborate with someone more technologically capable.

Analog artists tend to have a more hands-on mark-making process, primarily involving direct tactile control over the art object. Digital mark-making can feel foreign to these artists because manipulation of the art object is mediated by a mouse, keyboard or trackpad. The lack of physicality in digital art contributes to a limited sense of expressive control for analog artists.

1.3.2 - Act of Expression

Artists often describe the act of creating a work as an ongoing conversation with the piece's spatial components. John Dewey similarly describes this expression as a “spatial impulsion” that “designates a movement.”[15] For a painter, the canvas serves as a spatial context in which the mark-making impulse occurs. For any artist working within AR, the spatial context lacks such overt boundaries. Familiar environments and objects around us emerge as “coefficients in new adventures” instead of growing “stale from routine or inert from lack of use.” [15] As new digital media develops, Dewey reminds us to consider its “intrinsic” connection to the act of its expression.
1.3.2 - Expressive Marks

The following study seeks to develop an accessible tool in the AR medium that encourages spatial expression throughout the creation process. Starting with a simple line drawing tool and placeable 3D objects, we intend to equip creatives with non-technical backgrounds to intuitively make expressive mARks in conversation with surrounding spaces. Furthermore, we wish to empower analog visual artists to build upon the significance of their work with a new kind of mARk.

2. Related Works

2.1 - Prior Research

2.1.1 - Ivan Sutherland

*Figure 2.1: Ivan Sutherland using sketchpad in 1963.*
Ivan Sutherland pioneered the creation of mixed realities and digital drawing. Developed in 1963 as Sutherland's Ph.D. thesis at MIT, Sketchpad was the first interactive computer-aided design (CAD) system. It allowed users to create and manipulate graphical objects directly on a computer screen using a stylus. Sketchpad laid the groundwork for modern CAD systems, 3D modeling software, and graphical user interfaces (GUIs), revolutionizing the way people interact with computers. By enabling direct manipulation of graphical objects, Sketchpad made it possible for non-programmers to use computers for design, leading to the initial democratization of digital art production. [16]

In 1968, Sutherland invented the Sword of Damocles— the first head-mounted display and an early example of AR technology. The device tracked the user's head via a mechanical arm suspended from the ceiling. Primitive computer graphics were superimposed on their view of the real world— a significant step towards immersive computing. [17]

Ivan Sutherland was undoubtedly ahead of his time. Sketchpad operated similarly to our modern Procreate, albeit with much more primitive functionality. Years later, consumers are still waiting on AR glasses to become more accessible. However, the ubiquity of smartphones has allowed for widespread use of mobile AR.
2.2 - Existing Software

2.2.1 - Adobe Aero, LightSpace and Artivive

Adobe Aero, LightSpace, and Artivive are three different Augmented Reality (AR) mobile applications that have features for creating immersive and interactive experiences. [18][19][20]

Artivive is an AR platform that allows artists to bring their traditional artwork to life with digital animations and effects. Specifically designed for artists and curators to create augmented reality experiences for their artwork, Artivive offers a simple and intuitive interface, making it accessible for users with limited technical knowledge. Artists can overlay digital content, such as videos, animations, and sound, onto their physical artwork, adding an interactive dimension. Primarily targeted at art museums, galleries, and educational institutions, the app features a web interface that allows users to upload images of their artwork and create AR experiences by adding other content, such as videos, animations, or 3D models.

Figure 2.3: Users can draw lines and place 3D models directly in an AR environment.
Adobe Aero is an AR creation tool that integrates with other Adobe software, such as Photoshop and Illustrator. Artists can import their existing 2D or 3D artwork or sketches and create AR experiences by positioning them in a real-world environment and adding basic interactivity.

LightSpace (formerly Paint Space AR) is another AR creation tool that enables users to draw and paint directly in their physical environment using AR technology. The app has limited functionality for unpaid users, but allows users to create 3D drawings and paintings that can be shared with others or saved as photos and videos.

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While these three applications offer exciting opportunities for creating in AR, they lack the specific qualities we seek in a tool for analog artists who wish to preserve their work. (Table 1) Our solution seeks to incorporate the successful features of these applications– Artivive’s focus on interdimensional work, Aero’s intuitive object placement and retrievable assets,
and LightSpace’s delightfully energetic drawing process— in an attempt to provide creators with a more robust tool for engaging AR composition.

3. Technical Solution

3.1 - Product Overview

Crayon is a mobile app built in Unity designed for creatives with limited technical knowledge to explore inter-dimensional (augmented reality) art. All of the functionality of the application exists within panels accessible from a navigation bar at the bottom of the screen. The navbar includes a) a stackable/collapsible menu with trash and save buttons, b) a sketchbook of saved prior creations from anyone using the app, c) color panel control for lines and objects, d) tool controls for line drawing or object placement, and e) an undo button.

At the bottom of the tool panel (d), the user can toggle between the line and object tools. In line mode, users draw lines by touching the screen and dragging it through space like an invisible marker. The system detects where the physical phone is relative to the AR environment and adds points to the line accordingly. The line customization controls include thickness adjustment and four “brush” textures for drawing through space: normal, dither, pastel, and glow. Object mode works similarly. The system detects the user’s mobile position and places the object on touch. Object customization provides four primitive shapes that users can distort to their liking using scale sliders.
3.2 - System Architecture

3.2.1 - Overview

System managers in the Unity scene handle all internal and external processes, while scriptable objects in the project file store all custom tool data. NavManager toggles and
activates the line tool vs the object tool. ColorManager updates the colors stored in LineSettings and ObjectSettings whenever the palette selection changes. LineManager and ObjectManager handle each tool’s settings, respectively. ARDrawManager is the primary script facilitating the actual drawing/instantiation during each session, along with LineSettings and ObjectSettings, of course. Persistency within the application is controlled by the DataManager and FirebaseManager, with help from ARScreenCapture upon saving to the sketchbook..

Using separate managers and scriptable objects for each core function within the app allows for greater modularity in the system, making for a cleaner development experience, final product and future expansion.

3.2.2 - making mARks

![Diagram showing managers connecting UI panels to object settings]

**Figure 3.3:** Managers in the scene connect UI panels to the scriptable object settings for tool customization.
Upon opening the app, the ARPlaneManager (provided by ARFoundation) starts looking for surfaces via camera, adding them to the scene as GameObjects. This orients the app within your environment. Once it’s detected at least one plane, the user can begin to add lines and objects to the scene by creating AR Anchors in relative space. AR Anchor is a class provided by ARFoundation to track the positions of real and virtual objects relative to the camera.

The managers involved in connecting the UI to the tool settings stored in scriptable objects (LineSettings and ObjectSettings) include the NavManager, ColorManager, LineManager and ObjectManager. NavManager allows the user to control which tool is active in the scene and moves the UI selector accordingly. ColorManager connects the active color selection to the preview rectangle as well as the color properties stored in LineSettings and ObjectSettings. LineManager facilitates customization of the line tool, including adjusting the width or switching materials (normal, dither, pastel and glow). Similarly, the ObjectManager handles size adjustments and object selection.

**Figure 3.4:** Upon user input, the DrawOnTouch function in ARDrawManager uses the settings to create new mARks in the scene.
On every frame, the ARDrawManager checks to see if a user is touching the screen. If so, the function DrawOnTouch() instantiates whatever line or object is active in the scriptable settings. It creates these GameObjects using the user’s position as the AR Anchor transform, which orients itself in a local frame of reference according to the planes detected. The manager also has other functions for manipulating art objects within the scene view. GetAllLinesInScene() returns a list of everything tagged as a line, allowing two other functions in the manager ClearLines() and Undo() to easily access this information.

```csharp
DrawOnTouch()
{
    for each tap:
        get the touch position
        if touch phase has just begun:
            make a new AR Anchor
            if the line tool is active:
                make a new game object
                give it a line renderer
            else if the object tool is active
                and the object has not been spawned yet this touch:
                Instantiate object at touch position
                set spawned object boolean to true
                update the objects properties to match settings
            else if the touch phase has already started
                and user has moved position:
                If the line tool is active:
                    Add a point to the existing line renderer
                else if the touch phase just ended:
                    reset the spawned object boolean
}
```

3.2.3 - Saving mARks

Drawing persistence crucially allows artists to revisit their creations in later sessions and distribute them once they are finished. This process of converting data into a form that can be stored is known as serialization.

**Figure 3.5:** Upon tapping “save,” the DataManager serializes drawn items in the scene and saves them to Firebase Realtime Database through the Firebase Manager.
The DataManager controls the functions that serialize mARk data within the scene. When the app starts, DataManager begins to “listen” for the save button to be clicked. On click, it creates a new serializable drawing from the scene and sends it to the FirebaseManager to upload to the RealtimeDatabase.

SaveCurrentDrawing starts by creating a serializable list of all line data in the scene by calling CollectLineDataFromScene. The helper function first creates an empty list of the serialized LineData type as well as a populated list of LineRenderers within the scene view. It then iterates through the list of identified line renderers, converting each line into the custom serializable LineData type and adding it to the list created at the beginning of the function. CollectLineDataFromScene ultimately returns this list to SaveCurrentDrawing. As it serializes each line in this list, CollectLineDataFromScene calls another helper function to serialize Vector3 positions and rotations as the VectorData type and

```java
public void SaveCurrentDrawing() {
    List all of the LineData
    List all of the ObjectData
    Generate unique drawing ID
    Create drawing object
    Cast it to JSON
    Store the drawing object in FireBase
}
```
to serialize line’s Color information into the serializable ColorData type. CollectObjectDataFromScene() works the same way but handles all 3D objects instead.

Once the data has been converted, DataManager calls FirebaseManager to turn it into a JSON and store it on a realtime database. The system stores JSON drawing recipes on the Firebase Realtime Database instead of binary serialization to afford more universal applications of each drawing. By saving each drawing as a parseable JSON with generic vector, color, size and material data, the drawings become software-agnostic. The use of a realtime database also affords streaming social drawing sessions in future versions.

Immediately after uploading the drawing JSON, FirebaseManager calls ARSceneCapture to capture a snapshot of the drawing at the moment of upload. Firebase Realtime Database cannot store the snapshot files, but Firebase Storage can. So once the snapshot is captured and returned to FirebaseManager, the file is uploaded to Storage, and the realtime database stores the image URL as a string in the drawing JSON that has just been created.

3.2.4 - Retrieving mARks

![Diagram](image)

**Figure 3.7:** When a user taps on a drawing in the sketchbook, FirebaseManager pulls the drawing’s JSON data from the cloud, deserializes it, and instantiates it within the scene.
In the sketchbook, each drawing image acts as a button to instantiate that drawing in the current scene. It does so by calling a function that loads the drawing based on the drawingID associated with the tapped image. FirebaseManager pulls the raw vector/object data from the JSON, deserializes it into our custom classes, and then iterates through that deserialized data to instantiate the relevant line renderers and objects.

3.1.5 - Technological Reproducibility: Non-Fungible JSON

Storing each drawing as a JSON strategically aligns with how Non-Fungible Tokens (NFTs) are structured on the blockchain. Each NFT contains JSON metadata describing its unique properties, including its name, description, creator, and link to the asset’s file or content (e.g. image, video, audio, or 3D model).

As NFTs rise in popular culture, critics question their use value, especially with bitmap artworks (jpeg, png, etc.). After all, what is the difference between accessing the original work’s png file via blockchain and accessing an identical screenshot copy of that work? Both bitmaps look the same, the only difference being that we psychologically perceive one to be the original. Unlike the bitmap, one cannot replicate the experience of an ARtwork via screenshot. To view an ARtwork, the user must have access to its original recipe in order to re-render it within their environmental context. Storing each drawing’s recipe as a JSON allows us to seamlessly create its unique existence, providing stringent control over its reproduction.
3.3.1 - User Experience in AR

One of the limitations of current digital art tools is their tendency to encourage sedentary acts of expression, often limiting the artists’ physical movements to minimal motion control of a mouse, keyboard or stylus. In fact, before playing with an initial prototype of this tool, Turiya Adkins (an abstract oil and acrylic painter) avoided digital tools. The physical engagement required to create while using Crayon felt more akin to the feeling of painting with a brush than, for example, using Adobe Photoshop. This new method of creation enticed Adkins, as it offered her a new way to connect with her own work. Surprised by her own interest, she agreed to actively participate in the development of this tool.

A defining quality of AR is its ability to connect us to the physical world rather than absorbing us into a new/completely virtual one, so the UX needed to be minimally invasive. Common practice in traditional mobile app design centers around creating a clean,
self-contained user experience and interface. Self-contained refers to the idea that most mobile applications do not need to consider the user's physical environment as a factor within its design. By contrast, the successes and failures of any AR product design fundamentally rely on the interaction between the app's UI/UX and the spatial context in which the user engages. Thus, it was determined that the layout of CrayonAR should not feel like a mini, self-contained product within a phone screen, but should rather emphasize the phone's relative placement in the “real world.” Satisfaction of this design hinges on its ability to connect the user to an invisible layer within the “real world” and whether it can provoke spatial curiosity.

An important consideration has been to implement the app in such a way that allows for future development of different versions for different use cases. For example, an artist may want to use it to create a work, but the artist (or museum or gallery) may want access to the same database to view this work without having the creation tools available. With this in mind, I identified the need for a modular design system with custom and easily reusable views.

3.3.2 - Early Prototypes

The very first prototype for this project was developed during a group project for COSC 63: Development in AR and VR. [21] Inspired by the magical three-dimensional drawing in the children’s book Harold and the Purple Crayon, my partners and I developed a version of this app that allowed users to draw through space by tapping the screen and instantiate objects and particle systems using hand gestures facilitated by the ManoMotion APK. The final class prototype featured an ARAnciorn system designed in part by Youtuber Dilmer Valecillos. For this version, my group mates and I developed a similar line creation tool, but we
expanded upon it considerably in order to include custom colors, line thickness, objects, and particle systems. [22]

Figure 3.9: Early prototype used the ManoMotion Hand Gesture APK to instantiate particle systems and objects.

Following the success of our final project, I set out to develop a more comprehensive tool for artists specifically. The design for MVP 2.0 originally featured a robust set of options including user accounts, a landing page for switching between views, and an individual sketch gallery as well as a community library of sketches.
It also included designs for a QR scan-to-access feature for users with or without accounts who happen upon a public viewing experience. Users had to be in “creation mode” to make new sketches or expand upon old ones. There were four different options for creating marks, five if you include the ability to instantiate your own previously saved sketches.

Based on the parameters of versatility and minimal invasiveness, we implemented a system of panels for each feature. The panels could pop in or out of view depending on when a user wants access to their functionality. Modularizing each feature into its own panel UI streamlines the user’s actions at any given moment by reducing their optionality and thus cognitive load. By minimizing the amount of extraneous information presented to users using a particular tool, the panel system allows for a less distracting, more seamless
integration of UI into surroundings. The panels intend to function as palettes within an ever-expansive canvas.

![Figure 3.12: Figma prototype for the second iteration of the app.](image)

3.3.3 - Refinement

After showing a group of analog artists the product overview and Figma prototype, it was recommended that I simplify the app’s capabilities for the initial collection of usability data. Many found the system and potential user flows overwhelming and confusing and suggested that the QR scan to load, multiple sketch libraries, and graffiti plane spray features may clutter the user’s initial experience. A 22-year-old sculptor with limited technical experience aptly noted that “if you’re interested in seeing how and if people use the tool to create, make sure you focus their attention on the act of creation.”
Considering this feedback, I paired down the functionality to align with the core demographic’s mark-making needs. Spray paint and particle systems were eliminated from the application. Spray painting confused people because the mark-making worked differently from the other tools, as the texture adhered to detected planes in the environment rather than anywhere in space. Particle systems did not confuse people, but they were infrequently used, perhaps due to their previous associations with these forms (fire, sparkles, and fog). Compared to lines and primitive objects, particle system marks promoted less freedom for abstraction.

Since the retrievability of sketches is essential to the experience, I kept that feature but combined all sketches into one library and removed the unnecessary spawn button from the view. Users instead directly tap on the sketch to instantiate in the current scene.

The relativity of color perception based on the presence of other colors made the approach to the color of UI in AR more nuanced. [21] In traditional UI design, one has full control over the context in which colors emitted by the screen will be perceived. Since the UI is not destined to be superimposed over a camera view, the designers have the power to make the final decision about the color relationships users see. Similar to painters, product designers balance the color of UI by balancing the “interaction of colors” within. [23]
In the initial MVP, the design considered this phenomenon by using a UI exclusively consisting of a grayscale palette. However, as any painter would know, gray colors are at risk of including soft traces of specific hues. These chromatic grays can be subtle and consciously imperceptible while subconsciously impacting our experience of color relationships. To avoid this altogether, the following prototype eliminated the use of gray throughout the UI, instead using true black with various opacities.

Furthermore, the dimensionality of the user interface was flattened in the next iteration of the app. In the initial prototype, the UI buttons were given a subtle gradient to imply tap-ability to users. However, upon using the app, it became clear that this 3D button design pattern is not as successful in AR applications. For non-AR apps, the spatial dynamics within the user interface are entirely confined within the application. In AR apps, the embedded nature of the app within an existing world implicates the spatial relationships within the user interface.

4. Results

This particular study primarily focuses on the general usability and whether the experience of the application provokes spatial exploration and delight. A total 20 individuals participated in the test: 18 of them were between the ages of 20 and 30, while the remaining individuals were 40+. Included in this bunch were 4 painters, 2 sculptors and 1 architect. The group was instructed to explore the app freely within any environment for at least 5 minutes. They were asked to try out every button, but did not specify what the buttons do. Upon completion, the group anonymously completed a survey that included eight questions on a linear scale of 1-5 and four short responses.
4.1 - Survey Feedback

4.1.1. - Enjoyment and Usability

Enjoyment and usability were both rated on a scale of 1 to 5. On a 1-5 scale of “Hated it” to “Loved it,” the average enjoyment rating was a 4.5 (or 91%). On a similar scale of “Difficult and Confusing” to “Easy and Intuitive,” the average usability rating was a 3.7 (or 74%). 11 users rated enjoyment at 100% while only 3 users rated usability 100%. With n = 20, the median ratings for enjoyment and usability were 5 of 5 and 4 of 5, respectively. Evidently, the average user found the app slightly more enjoyable than usable.

**Figure 4.1**: Overall enjoyment of the experience. (n=20)
Figure 4.2: Overall usability of the app. (n=20)

Figure 4.3: Overall usability of the line tool. (n=20)

Figure 4.4: Overall usability of the object tool. (n=20)
Participants reported that the line tool is 15% more intuitive than the object tool using a scale of 1 (difficult and confusing) to 5 (easy and intuitive). With n=20, the average rating for the line tool was 4.2 of 5 (84%), while that of the object tool was 3.5 of 5 (69%). The median ratings for each tool were 5 of 5 (100%) for line and 3 of 5 (60%) for objects.

When asked about what they liked about the experience, 80% of participants (16 of 20) mention that the tool allowed them to engage with their surroundings in a novel way. One participant said that it “made me interact in my living room differently” and another noted that it “immediately made me get up and move around the room.” The latter participant also “liked to see the trails stretch out across [their] entire apartment.” 55% of participants explicitly appreciated that the lines and objects remain in relative space.

The app seemed to inspire a transcendent creativity across the board. One user noted that it “felt magical,” while another described a sense of “no intense boundaries.” Another participant went as far as to compare this experience with being in “[their] own Yayoi Kusama world,” a reference to the influential artist’s series of infinity mirror rooms, which “transcend the physical limitations of her own productivity.” [23] The reference to Kusama demonstrates another common theme in the user feedback—the joy and “fun of being lost.” The same user who commented on the “magical” nature of the experience also described “[complete immersion] into [their] phone to the point where [they] lost connection to [their] surroundings.” They found drawing and going behind it “surreal.”
One user responded well to the “beautiful color spectrum, elegant without extraneous features that would hamper the experience” as well as the “options for different brush strokes and shape options.” They found the gallery fun for the “social element/collective experience.” Two other participants also enjoyed “the ability to view/upload other people's drawings.”

There were practical uses suggested for the tool, too. “As a professional,” wrote an architect, “I can immediately see how this tool can be immensely useful in expressing ideas on site. I'm excited to see how this will be used as a visualization tool. I'd like to try it on bigger format screens like iPad or tablet.” A sculptor mentioned it could be useful to “draw their pieces on paper and then want to see how that drawing translates in space.”

![Image](image.png)

**Figure 4.6: “What did you dislike about the experience?”**

When asked about what they did not like about the experience, 50% of participants (10 of 20) expressed frustration with the UI menu system—specifically the fact that the menus did not automatically close upon switching tabs. One user mentioned that “when they overlapped it looked messy” and that they “expected it to close” upon tapping above the UI panel. Another wished for “automatic minimization.”

Responses were mixed regarding the intuitiveness of the design. One person reported that it was “difficult to get the hang of things,” while another thought the experience was “fun and intuitive.” Someone commented that “the gallery feature isn’t immediately intuitive,”
suggesting the addition of some form of instruction. Another participant expressed a similar desire for guidance in the form of a “disclaimer” that users should “stand up and move around” for the plane detection to kick-off the experience.

4.1.2 - Toy for Play vs. Tool for Art

Figure 4.7: Did the app feel more like a “Toy for Play” or a “Tool for Art”?

55% of participants (11 of 20) were split between whether they thought the app more closely resembled “a tool for play” or a “tool for art,” suggesting a balance between the two qualities. 30% of participants (6 of 20) felt the app was more of a toy for play, while the remaining 15% of (3 of 20) felt it more a tool for art. The average rating was 2.8 of 5, leaning just +6% towards “a tool for art.” The median and mode were both 3 of 5.

Multiple people elaborated on their perspective in the general comments. One individual commented that “this falls right between toy and tool!” This person “appreciated the playfulness of it and how naturally it causes you to move around in ways you wouldn’t otherwise.” Someone else was “compelled by the dichotomy between something being a tool
for art vs. a toy for play.” They found the tool “strikes that perfect balance in that it takes the form of an app and its association with entertainment, fun, play, leisure, etc. and builds a tool for art-making in an AR environment … The outcome is something that feels like both a toy and a tool in a historically unique way.” They conclude with a question: “does crayonAR suggest that the future of art and the digital aspects of the medium harkens a synthesis of tool and toy? Of the aesthetic and the everyday? Of the creation of art and the right to play?”

4.1.3 - Spatial Engagement

**Figure 4.8:** How physically engaged was your body while using the app?

![Bar chart](image)

Participants were asked to pay attention to their physical movement. Nearly half of the group (45%) reported experiencing 100% physical engagement, with the average score of 3.7 of 5 (74%) and a median of 4 of 5 (80%).

In the short form response, people described their interactions with surrounding space more specifically. One person described the app as a “tool that makes you more observant of your surroundings despite being through a phone screen.” Users were excited to “build
things into a physical space” and “bring a daydream to life.” They enjoyed the relative permanence of objects and found it “amazing that the information stays in place even after leaving and revisiting the space.” The experience disoriented two participants. One of them did not have a “good sense of where exactly in space” they were until they “stepped back and did a 360 around the drawing.” The other participant “got lost but it was fun to be lost.”

4.2 - Case Study with Painter Turiya Adkins

4.2.1 - Interdimensional Paintings

As previously mentioned, abstract painter Turiya Adkins has historically resisted using digital tools with her work. However, the invisibility of augmented reality and physicality of the phone as a brush inspired Adkins to test the medium. Adkin’s work explores the tension between the visibility and invisibility of the Black body. Compelled by new possibilities for “world building,” she set out to use Crayon to create “new knowledge of invisible planes.” [25]

Figure 4.9: Painter Turiya Adkins’ interdimensional works-in-progress
5. Discussion

5.1 - Overview

Based on the results, the technical solution succeeded in facilitating novel spatial expression and surreal art experiences. Participants of various backgrounds enjoyed using the app, despite several issues with usability. Such concerns were relatively straightforward and easily addressable in future iterations, with the primary complaint being that the panels would not automatically close after changing a setting. Difficulty with the object tool could also improve, as the average usability score was a 3.5 of 5 and the most common response was a 3 of 5.

5.2 - Art as Experience

The application inspired whimsy by animating users’ curiosity and creativity within familiar environments. While inevitably in part due to the novelty of the AR technology itself, several people described the sensation as “magical” and playful. This sentiment was especially demonstrated by the individual who compared the experience to those created by Yayoi Kusama, known for her playfully imaginative worlds and disorienting infinity rooms. [24]

People of all artistic and technical backgrounds found the app engaging and enjoyable, indicating the app’s potential to democratize the art experience and make it accessible to a wider audience. Everyday objects became new visual characters, transforming identity and igniting creativity, blurring the lines between the aesthetic and the everyday.
Considering the comparison to Kusama, it made sense that participants reported the app felt like both a toy for play and a tool for art. The neutrality of the quantitative and qualitative responses to this question remind us that there need not be such a rigid distinction between whether something is playful or artful. Art often emerges from play, as Kusama has proven time and time again over the course of her career. This notion also resonates with John Dewey’s advocating for the accessibility of art and its integration into everyday life. [26]

This thesis originally set out to address the need for an artistic tool for artists with non-technical backgrounds, with this user testing endeavor serving as an assessment on the prototype’s general usability. However, it appears that perhaps a stronger purpose of this current iteration is to introduce a playful digital toy that compels users to engage with their surroundings unlike many other fun mobile apps that isolate the user via phone. The ability to store these drawings unlocks new potential for painters and other artists, but the artfulness of the product focuses less exclusively on the user’s ability to create an explicit commodity.
6. Conclusion

6.1 - Limitations

Perhaps the most significant limitation to the information presented in this paper is the small sample size of users. Only 20 people participated in the survey, making it difficult to glean statistically significant insights from the data. Another limitation of the study is that it only surveyed mobile AR creation, which is currently the most ubiquitous AR technology.

6.2 - Future Work

Strategic limitations to the initial MVP helped identify preliminary understanding of the user's experience of the tool. However, now that a baseline understanding has been established, there are several iterations that should be integrated and tested. Subsequent versions of this app should automate menu closing, improve object placement, expand upon tool customization and incorporate a comprehensive first time user experience.

6.3 - Conscientious Use

Despite the excitement to explore new inter-reality possibilities, there are some concerns regarding its widespread adoption. Ultimately a screen is a screen, even if it engages you with the surrounding world. As one user noted,

“even if I’m seeing something on the screen look real and as if it could exist in real life 3D, I’m still looking at it thru the screen and it feels like 2d to me. Like watching a video of something happening. It’s not necessarily an
awareness of the phone but more so watching things on the screen doesn't capture the experience of real 3d things."

As new technologies make AR creation more accessible to non-digital artists, it may be tempting to hop on the bandwagon just because it’s an exciting new thing. But as wisely cautioned by philosophical technologist Margaret Boden, “it is not enough simply to be novel.” [27] We must be deliberate about the artistic contexts in which to blend realities, ensuring that the digital medium is used with intention and awareness of its psychological impact.
## Appendix

### A. Survey Results

<table>
<thead>
<tr>
<th>Timestamp</th>
<th>Overall Usability of the app</th>
<th>Overall enjoyment of the experience</th>
<th>What did you like about the experience? (Explain sentence welcome)</th>
<th>What did you dislike about the experience? (Explain sentence welcome)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/21/2023 22:41:12</td>
<td>4</td>
<td>4</td>
<td>Of course it was fun and intuitive and made me interact in my living room differently</td>
<td>UI could be faster</td>
</tr>
<tr>
<td>4/21/2023 1:34:55</td>
<td>5</td>
<td>5</td>
<td>It immediately made me get up and move around the room. I liked how the whole space and my entire apartment felt</td>
<td>I think there should only be 1 UI panel open at a time. I was able to open a few at a time and when they overlapped it looked messy. Also when I tapped above the UI panel I expected it to close</td>
</tr>
<tr>
<td>4/21/2023 12:34:41</td>
<td>4</td>
<td>4</td>
<td>The drawings stay in place - the user has a lot of control</td>
<td>I wish one menu would close when you open another menu</td>
</tr>
<tr>
<td>4/21/2023 15:44:32</td>
<td>4</td>
<td>5</td>
<td>I like that the object is fixed in the space. It’s drawn all over and when I turn the phone 360 degrees it’s easy to fix the object at which it was drawn. I like the different colors and features</td>
<td>It didn’t seem like using objects as much, maybe because you don’t get a preview of the size of the object before using it so it just surprised me with the shape when I put it on the screen</td>
</tr>
<tr>
<td>4/21/2023 18:01:43</td>
<td>4</td>
<td>5</td>
<td>Drawing and turning and seeing it from another perspective</td>
<td>The drawings didn’t stick perfectly sometimes when I drew them</td>
</tr>
<tr>
<td>4/22/2023 13:41:43</td>
<td>5</td>
<td>5</td>
<td>- you can do whatever you want, no interface boxes</td>
<td>Two menus could be up at one time</td>
</tr>
<tr>
<td>4/22/2023 13:48:25</td>
<td>3</td>
<td>3</td>
<td>- a little confused about exactly what I was supposed to be doing</td>
<td>I was a little confused about exactly what I was supposed to be doing</td>
</tr>
<tr>
<td>4/22/2023 14:12:01</td>
<td>3</td>
<td>4</td>
<td>Enjoyed how permanent the objects were once you repositioned them</td>
<td>It didn’t work until I stood up and moved around, so a disclaimer would’ve been nice. I also don’t love the preset objects (cone, etc.)</td>
</tr>
<tr>
<td>4/22/2023 14:12:07</td>
<td>2</td>
<td>4</td>
<td>Interesting concept and cool to draw things in my space</td>
<td>Difficult to get a hang of things and not very customizable</td>
</tr>
<tr>
<td>4/22/2023 15:24:39</td>
<td>4</td>
<td>4</td>
<td>I got lost but it was fun to be lost</td>
<td>I wish the pop up menus would automatically minimize when you close them</td>
</tr>
<tr>
<td>4/22/2023 15:57:46</td>
<td>2</td>
<td>4</td>
<td>I got lost but it was fun to be lost</td>
<td>I have no idea what I was doing</td>
</tr>
<tr>
<td>4/22/2023 19:28:36</td>
<td>4</td>
<td>4</td>
<td>Adaptive to any environment, beautiful colors, spectrum, except without extraneous features that would clutter the experience. Fine options for different brush strokes and shapes, etc.</td>
<td>The gallery feature isn’t immediately intuitive to me, i.e. maybe a brief intro box somewhere to explain what the pictures are, how to save different pictures, what purpose the function is to use already made drawings in your own environment?</td>
</tr>
<tr>
<td>4/22/2023 12:17:55</td>
<td>3</td>
<td>4</td>
<td>The color wheel options were awesome</td>
<td>It was a little glitchy and it didn’t save my objects in the exact right place</td>
</tr>
<tr>
<td>4/23/2023 12:30:17</td>
<td>4</td>
<td>4</td>
<td>I liked that your drawings stayed static on the screen even when you moved it around. It made me feel like it could bring objects into my environment in the physical world. I also liked that</td>
<td>Depth perception needs improvement, and it would be cool if it could calibrate to certain points in space. Like snap onto corners of room or physical objects like furniture to calibrate the drawing board</td>
</tr>
<tr>
<td>4/23/2023 14:28:42</td>
<td>5</td>
<td>5</td>
<td>Fun to use and play around with. Existing to see potential for this type of tool. Amazing that the information stays in place even after leaving and returning the space</td>
<td>Didn’t know what to expect so was pleasantly surprised with the colors and shapes</td>
</tr>
<tr>
<td>4/23/2023 14:41:55</td>
<td>3</td>
<td>4</td>
<td>I got lost but it was fun to be lost</td>
<td>Meta options not automatically disappearing when the next option was selected (they overlapped each other)</td>
</tr>
<tr>
<td>4/24/2023 15:16:29</td>
<td>4</td>
<td>4</td>
<td>I liked how it felt like my own Yunnan kusama world. It was building a room size installation. It felt fine and it was easy to begin channeling my creativity Cool to be able to move around and have my drawings stay in place. Liked having the option for different line thicknesses, colors and shapes.</td>
<td>I don’t like how the different toolboxes overlap one another. Once should auto-populate when you open another.</td>
</tr>
<tr>
<td>4/24/2023 20:01:32</td>
<td>3</td>
<td>3</td>
<td>Wish there were thinner lines, option screens overlapped my hand in the way</td>
<td>Wish there were thinner lines, option screens overlapped in the way</td>
</tr>
<tr>
<td>4/24/2023 20:43:45</td>
<td>4</td>
<td>5</td>
<td>Ability to view other people's drawings</td>
<td>Multiple options fails open all at once clutters screen</td>
</tr>
<tr>
<td>4/24/2023 22:42:59</td>
<td>3</td>
<td>4</td>
<td>It was fun to draw on the phone around and see how what I created moves and changes in space</td>
<td>Sometimes felt in the way, couldn’t slide the tools, down to make them disappear so you could create,</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean</th>
<th>3.65</th>
<th>4.45</th>
<th>4.45</th>
<th>4.45</th>
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<td>Median</td>
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<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
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<tr>
<td>Mode</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Usability of line tool</td>
<td>Usability of object tool</td>
<td>Any specific feedback?</td>
<td>How physically engaged were your body while using the app?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
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<td>----------------------------------------------------------</td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td>4</td>
<td>The depth at which the line was drawn was sometimes surprising to me. I know that maybe it is just some set number of units away from the phone, but I didn’t feel I had a good sense of where exactly in space I was drawing until I stepped back and did a 360 around the drawing.</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>I don’t like using objects as much, maybe because you don’t get a preview of the size of the object before using it so it just surprises me with the shape when I put it on the screen. Would be cool to be able to start drawing before closing out the line tool/object tool.</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>Overlapping views UI bug</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>solid lines became translucent after switching from the light brush - wasn’t sure how to fix this.</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>Did I miss direction?</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>Assuming everything is still limited because it’s a beta version, but in future versions I’d like to see more pen shape options, options for opacity, calibration of space for depth perception within app, number scale for reference in the XYZ sliders for shapes.</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>Overlapping toolboxes wasn’t very orderly.</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Would like if icon were highlighted when selected.</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>Would like if icon were highlighted when selected.</td>
<td>4</td>
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<tr>
<td>5</td>
<td>3</td>
<td>Would like if icon were highlighted when selected.</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.2</td>
<td>3.5</td>
<td></td>
<td>3.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td></td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td></td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Did the app feel like a toy for play or a tool for art?</td>
<td>How aware were you of the phone in your hand while CREATING the work?</td>
<td>How aware were you of the phone in your hand while REVIEWING the work?</td>
<td>If you have any general comments, I'd love to hear them.</td>
<td></td>
<td></td>
</tr>
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<td>I think in order to see the app more as an art tool rather than a toy, I would need more control/knowledge over the distance from my phone in which the lines are being drawn. I would also potentially need more line options (maybe even thinner lines than what is allowed right now for line thickness), and an eraser in addition to undo button.</td>
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<td>While I was &quot;completely distracted by the screen&quot; it's cause even if I'm seeing something on the screen look real and as if it could exist in real life 3D, I'm still looking at it thru the screen and it feels like 2D to me. Like watching a video of something happening. It's not necessarily an awareness of the phone but more so watching things on the screen don't capture the experience of real 3D things.</td>
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<td>1 Drawing and going behind it was surreal</td>
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<td>1 So cool! I guess I'm not an artist so I didn't have too much to draw but I can imagine someone with a creative brain loving it.</td>
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<td>3 I think this falls right in between toy and tool! I can see this as being super useful for sculptors who have drawn their pieces on paper and then want to see how that drawing translates in space (the camera sensitivity makes it hard to get accurate drawings though). I also appreciated the playfulness of it and how it naturally causes you to move around in ways you wouldn't otherwise. Also a tool that makes you more observant of your surroundings despite being through a phone screen.</td>
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<td>I really liked the questions about awareness as it was a large part of my experience using this tool. I found that I would tend to draw objects into the context of my the space I am in, so my awareness was very high. I think this would be a cool tool to have when trying to build things into a physical space or help bring a daydream, alternate reality come to life. The way the objects moved in relation to the camera was the most impactful element of this app for me - I feel like this app could be viewed interchangeable as toy/tool based on the users intentions.</td>
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<td>3 I personally have a hard time overcoming the technology gap. I'm not much of a phone user, so drawing on screens has always been difficult for me. As a professional I can immediately see how this tool can be immensely useful in expressing ideas on site. I'm excited to see how this will be used as a visualization tool. I'd like to try it on bigger format screens like iPad or tablet when I get the chance to.</td>
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<td>The drawings don't quite stay in place and the ability to erase specific segments not just undo would be useful. Overall very cool experience that I could see widespread applications for!</td>
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B. Sample Works from User Testing
C. Additional Charts

How aware were you of the phone in your hand while REVIEWING the work?
20 responses

How aware were you of the phone in your hand while CREATING the work?
20 responses
Works Cited

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Figure References

[Figure 1.1] AR Pokemon Go

[Figure 2.1] Ivan Sutherland using sketchpad. https://bimaplus.org/news/the-very-beginning-of-the-digital-representation-ivan-sutherland-sketchpad/

[Figure 2.2] Ivan Sutherland using the “Sword of Damocles” https://www.researchgate.net/figure/The-Sword-of-Damocles-by-Ivan-Sutherland_fig2_291516650