The purpose of this study is to identify the factors that contribute to and detract from the usability and experience of Tilt Brush. It compares usability issues between users with formal training in art, and users with no formal training. Twenty participants were observed creating artwork in Tilt Brush and interviewed about their experience. They also answered a questionnaire based on the System Usability Scale.

The data collected identified that conventions from 2D apps and a sense of presence in the 3D virtual environment positively impacted usability. A lack of control, issues navigating virtual reality, and a lack of familiarity with Tilt Brush negatively impacted usability. The group with formal training overall wanted more tools that increased control over the artwork than the group without formal training. Finally, the user experience of Tilt Brush was positively impacted by immersion, novelty, tools, possibilities, and potential as a creative outlet.

Headings:

      User interfaces (Computer systems)

      Human-computer interaction

EVALUATING THE USABILITY AND USER EXPERIENCE OF A VIRTUAL
REALITY PAINTING APPLICATION

by
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Introduction

As virtual reality (VR) develops as a technology, and its applications expand across domain areas, it is important to consider the usability of these applications and how interfaces are being designed in 3D spaces. As a technology that is quickly growing its potential for adoption, the question of how to approach usability and user experience for VR is still being researched. There aren't as well-established heuristics and principles for VR as there are for technologies like 2D web interfaces (Bowman, Gabbard, & Hix, 2002). This novelty means that there is room for exploration of how these interfaces can be designed.

VR may rise in adoption in the coming years, as costs of the technology go down and it becomes more easily available to the general public (Bowman & McMahan, 2007). As VR finds this wider adoption, it will be applied to a range of domains. VR's potential is being explored in areas like education, medicine, gaming, and art, meaning that this technology has potential to influence fields that benefit humanity.

One benefit of 3D virtual environments is that they provide opportunities to engage in an immersive environment and learn from tasks that could not be done with a 2D interface (Dalgarno & Lee, 2010). This is one of the benefits of using VR in an educational context. To apply this idea to Tilt Brush, there is a kind of immersion in its virtual environments that is not possible with similar applications in 2D interfaces.

Researching the usability of VR is important because it will help make these applications more effective. A well-designed interface can help an app be successful and

adopted by users. Conversely, a poorly designed interface is likely to frustrate users, putting them off from the app, no matter what novel benefits it may offer. Researching VR usability offers a way to combat this problem. Identifying and testing principles that can be applied to VR interfaces creates knowledge that can be used to make better VR interfaces in the future.

VR has interesting implications for the domain of art. 3D VR painting is a novel artform that artists express excitement about, due to the possibilities of working in such a medium (Keefe, Feliz, Moscovich, Laidlaw, & LaViola Jr, 2001). The experience of painting in 3D and essentially creating a painted 3D environment is form of artistic expression that would impossible or incredibly difficult using a technology other than VR. This could lead to unique works of art that could not be created or experienced in any other medium. Evaluating the usability of the tools that could help achieve this would help broaden the understanding of how VR interfaces can be designed to allow for the creation of art and the experience of art. Studying the usability of a specific app in depth may yield results that can be generalized beyond the particular application, contributing to the understanding of VR interfaces.

Tilt Brush is VR painting app that allows users to paint in 3D space within a virtual environment. Tilt Brush has been la

uded for its usability and interface (Ungerleider, 2016; "Tilt Brush", n.d.), which makes it a good candidate for a usability evaluation because it would be beneficial to learn what aspects of the interface make it such a usable app. There is value in understand what a VR interface does well in regard to usability, (as well as understanding what aspects of the interface could be improved). Since usability is a subjective quality, there

is always room for debate and discussion on how an interface could be improved.

Understanding the strengths and weaknesses of Tilt Brush could be applied beyond this

particular application, and could help inform the design of future VR applications,

especially in the area of VR art.

This leads to the main research questions of this study:

RQ1: What factors contribute positively to the usability of a VR painting app for

HMDs?

RQ2: What factors contribute negatively to the usability of a VR painting app for

HMDs?

RQ3: Are there differences in the usability of the app for users with formal

training in art and users without formal training in art?

RQ4: How did these factors affect enjoyment of the artistic experience for users?

Through exploring these questions, this paper identifies aspects of Tilt Brush's

design that contribute to both to its usability as an app and issues with its usability. This

paper also explores differences in usability for users that have formal training in art and

users that have no formal training in art. Finally, the last question identifies what factors

contributed to an enjoyable experience for users.

Literature review

Virtual Environments

Schroeder (2008, p. 2) argues for virtual reality and virtual environments to be defined as "a computer generated display that allows or compels the user (or users) to have a sense of being present in an environment other than the one they are actually in, and to interact with that environment." This definition provides an understanding of VR as a way of being immersed in an environment created virtually. Tilt Brush allows the user to experience a virtual environment and augment it with their own artistic creations. Kimer & Martins (1999) identify key characteristics of virtual environments: synthetic, 3-dimensional, multi-sensory, immersive, interactive, realistic, and with presence. These characteristics help conceptualize the virtual environment of Tilt Brush and how users will experience it.

A virtual environment can be understood a "world" generated by a computer that users can experience, interact with, and feel like they exist within. Instead of the 2D interfaces typical of software, the third dimension of a virtual environment imitates reality. Understanding the concept of virtual environments and how users can interact with them is important to understanding the design of VR applications.

Presence and Immersion

Presence and immersion are important virtual reality concepts. "Immersion is a description of a technology and describes the extent to which the computer displays are

capable of delivering an inclusive, extensive, surrounding, and vivid illusion of reality to the senses of a human participant" (Slater & Wilbur, 1997, p. 604-605). This definition is limited compared to the broader psychology literature, as it only related to VR in a VR environment, keeping it in a narrow scope for the purposes of this study. Siate & Wilbur describe presence "as a state of consciousness, the (psychological) sense of being in the virtual environment" (Slate & Wilbur, 1997, p. 605). The sensory experience of seeing a virtual world through a HMD and being able to move about it contributes to a sense of a presence, as the experience of existing in the real world matches the experience in the virtual world (Hacmun et al., 2018; Morie, 2008). These definitions help ground the discussion of these concepts. Morie (2008) notes that presence is hard (perhaps even impossible) to measure, and that instead researchers may be best off measuring factors that are indicators of presence.

These concepts have implications for how people can create and experience art created for VR. Stronger presence in a virtual environment was found to correlate with an "aesthetic experience" of art in that environment (Eber et al., 2004). Immersion in VR allows the user to experience being in a virtual world while still experiencing the real world, opening up possibilities for new experiences of being with ontological implications (Morie, 2008).

Bowman et al. (2002) note the importance of measuring presence in VR usability studies. This is a unique characteristic of virtual reality applications, and the way the user experiences being in the virtual environment the application provides is a key part of the experience. There has been a push for further research to be conducted on how the design of VR systems contribute to a user's sense of presence (Schuemie, Van Der Straaten,

Krijn, & Van Der Mast, 2001). Dalgarno & Lee (2010) also argue that presence and immersion are directly influenced by the fidelity of and interactions afforded by the environment. This means that the way the interactions in environment are designed is going to influence how present the user is an environment, making presence seem very related to usability.

Another important factor that affects presence is the experience a user has using their body to interact with the virtual environment (such as walking in the real environment and having their avatar walk in the real environment) (Slater, Usoh, & Steed, 1995). The way the environment is designed and the way the user experiences "being" in the environment will impact presence, which will in turn impact the experience the user has with the application overall.

Presence is an important consideration for a usability study, because the design and fidelity of the environment and the way users interact with that environment will affect how easy or difficult it is for the user to use that app. The way the users experience a sense of "being" in the environment and the way that environment is designed will impact how easy or difficult of a time they have using the app and whether their experience with it is positive or negative.

Interaction

Mine (1995) provides an overview of techniques that can be used to interact with computer interface controls in a virtual environment. He identifies five ways to interact in a virtual environment: movement, selection, manipulation, scaling, and virtual menu and widget interaction. He also identifies three ways to implement these interactions: Direct User Interactions, Physical Controls, and Virtual Controls. These concepts are applicable

to the way users interact with Tilt Brush. Tilt Brush uses several of these techniques. For instance, both Direct User Interactions and Physical Controls are implemented as ways of allowing users to move throughout the environment in Tilt Brush. A virtual menu is a crucial part of the Tilt Brush interface. Understanding the way interaction techniques are implemented in Tilt Brush is essential to understanding the usability of the application.

Manipulation tasks for VR are selection, positioning, rotation, and scaling (Riecke, LaViola Jr, & Kruijff, 2018). These tasks are useful for thinking about how users can interact with a VR interface. Identifying these tasks in Tilt Brush will be useful for understanding its interface and capabilities.

Traveling

Navigating the virtual environment is an important aspect of the VR experience. Bowman, Koller, & Hodges (1997, p. 45) define travel as "the control of user viewpoint motion through a VE [virtual environment]." Users can navigate through Tilt Brush by walking and by teleporting. Teleporting allows the user to go farther in the virtual environment than could be walked within the real world physical constraints of the VR hardware. Seven factors can be found in effective travel techniques: speed, accuracy, spatial awareness, ease of learning, ease of use, information gathering, and presence (Bowman et al., 1997). In a study comparing different techniques for traveling, walking in reality was identified as having the most subjective presence over walking in place and flying (Usoh et al., 1999).

VR Usability Studies

VR-ENGAGE is an application that is used to teach children geography. The usability of this application was studied by observing children use this application in a

classroom environment. A questionnaire to evaluate the likeability of VR-ENGAGE and compare it to other applications was also administered to the students (Virvou & Katsionis, 2008).

The Virtual Life Skills project is a training environment for people with learning disabilities to practice life skills. A usability study was conducted by observing users of these apps and giving them a questionnaire to fill out. The questionnaire was also given to usability experts to assess how usable they found the application and how usable they anticipated the users would find it (Cobb, Neale, & Reynolds, 1998).

Both of these studies use observation to understand the usability of the application. They also collect some form of input from the users designed to measure the usability of the application. These usability studies use methodologies that are similar to methodologies used for usability studies on 2D applications. Usability concepts can be applied to studies of VR usability, the difference is applying those concepts to VR applications and their particular characteristics.

VR Art

VR is a unique medium for artistic creation; artists can make a virtual environment that is itself the art. They can immerse people in their artwork using VR technologies. Artistic Virtual Environments are a type of virtual environment that is specifically a work of art. They are described as: "These art works are typically "experienced" using some form of immersive display technology such as . . . a head mounted display. In contrast to typical commercial virtual reality (VR) installations which are typically entertainment/arcade oriented, AVEs are primarily intended to be expressive" (Zimmerman & Eber, 2001, p. 75). This is the type of virtual environment

that can be created in Tilt Brush. The application is designed to give users the freedom to express themselves by painting in 3D.

VR art can be characterized by the ability to move throughout a 3D space and create art using virtual materials that are not bound by the rules of physics that exist for "real world" mediums of art (Hacmun, Regev, & Salomon, 2018). VR art creation is characterized by an immersive experience. VR art also allows the user freedom for self-expression, with the benefit of features afforded by a digital environment (such as the ability to undo a mistake through the interface).

Bates (1992) argues that VR should learn from established artforms and take more than interface considerations into account. This will allow VR to reach its full potential as an artform. This also suggests that a full understanding of artistic VR applications will take the overall experience of using the application into account.

When conceptualizing VR art, it is important to take into account the characteristics of VR and how that will impact the creation of the art as well as the experience of the art. The novelty of VR and the characteristics specific to that medium can lead to the creation of new types of artworks that take advantage of the unique capabilities of VR. It is important to understand those characteristics when designing interfaces to create art in a virtual environment. However, it is also important to learn from the interfaces found in established artforms. Merging these understandings will allow for better tools for creating VR artwork.

Benefits of Art/Creativity and Virtual Environments

Not only is VR art is possible and offers potential for novel artwork, it also has several potential benefits worth exploring. Virtual environments offer unique

opportunities for learning, allowing participants to engage in tasks that uniquely possible and uniquely engaging within the context of virtual environments (Dalgarno & Lee, 2010). 3D visualization technology was proven to be useful for helping industrial design, architecture, and interior architecture students collaborate in an educational setting (Camba, Soler, & Contero, 2017). The experiential nature of VR allows for engaging learning opportunities (Bricken, 1991). VR has been shown to offer a unique way of learning in relation to making sense of art (Antonietti & Cantoia, 2000). VR art could be useful for art education and

Art can be beneficial toward well-being. Art can have benefits for public health (Clift, 2012). Art can also help people cope with difficult emotions and provide benefits to people struggling with illness (Stuckey & Nobel, 2010). VR art may have applications in this domain as VR in general gains wider adoption. As more potential benefits of VR are identified, understanding the usability of VR applications becomes more important.

VR may provide a beneficial mode of art therapy (Hacmun et al., 2018). Using VR as a medium for art allows the user to be immersed in the environment and gives them control over environment. The novelty of VR as a medium offers potential for creative expression, which could be beneficial for therapeutic purposes.

Art can be beneficial for education, health, and well-being. It also provides an opportunity for new, thought-provoking experiences. Art in virtual environments offers an opportunity to experience a virtual space while still existing in the real world, creating the possibility of a new and unique experience (Eber, Betz, Davis, Crockett, & Sparacino, 2004). Morie (2008) also discusses implications and questions that arise from the experience of occupying both virtual space and space in the real world simultaneously.

Tilt Brush has potential to provide benefits similar to more traditional forms of art. As a VR technology it offers a novel artistic experience that may have unique benefits future research could explore. Tilt Brush could potentially be a tool used in art therapy or in an educational context. It certainly can be used to create works of art. In order to get that kind of value out of applications like Tilt Brush, it is important to make sure that they are usable and meet the needs of the artists and hobbyists that use them.

Issues in VR Art Usability

VR usability is specific to the capabilities and limitations of VR technologies. Choosing the right interface device for a VR app is a large consideration, as it greatly impacts the usability of a particular app (Bricken, 1991). The abilities of the equipment the app is designed for will have an impact on the interface and how users interact with it. How the interface works with the hardware of the VR system should be a usability consideration because of this.

Eber et al. (2004) discuss issues with how HMDs allow people to experience AVEs. This kind of technology is restrictive, as the user must wear the headgear, hold the controllers, and limit themselves to the area between the sensors of the system. A lack of awareness of the real environment while experiencing a virtual reality environment is a usability issue that is unique to VR (McGill, Boland, Murray-Smith, & Brewster, 2015). If one is moving around in a real environment while being immersed in a VR environment, issues can arise from being unaware of the real environment, for example the user could trip over the cords connected to the HMD they are wearing, or they could bump into a wall in their environment.

Clearly, virtual environments need to be designed in a way that takes the characteristics of the hardware into consideration, because it will impact the experience of using the application. Designing the way a virtual world operates requires making decisions that will deeply impact the usability of the app, as the behavior of the behavior of the virtual environment is determined entirely by the developer (Bricken, 1991). Understanding how the design of the virtual world impacts the usability of the application is an important VR usability consideration.

Mine (1995) identifies that placing a 3-dimensional menu within a virtual environment can be a challenge for usability. This is another issue specific to VR usability. Generally, menus are important to applications both 2D and 3D, but identifying a way to make it easy for users to select options from a menu in a (likely) unfamiliar virtual environment is a particular usability challenge.

Satisfaction is a key quality of usability (Nielsen, 2012). For a creative app like Tilt Brush, the importance of an enjoyable experience is critical. Measuring how satisfying the experience of creating a VR painting is, especially in the context of self-expression, would be important data about the usability of the application.

There have are arguments for considering art applications more in academic study. Oates (2006) argues that computer art should be studied as part of information systems research, even arguing that computer art is a form of information. His argument is that in viewing computer art as an information system, the field's understanding of what an information system is can be challenged and expanded. Trifonovaf, Ahmed, & Jaccheri (2009) look at the intersection of art and software engineering, noting that software developers need to develop tools that can meet artist needs. Understanding the

intersection of technology and art and how technologies can be designed to enable art are valuable goals for a usability study, as that can lead to better interfaces for creating art. One usability study focused on creative software by comparing the way experts and novices used Photoshop, a 2D art application. The tasks in this study were selected to be as close as possible to tasks that these users would use Photoshop for in their regular lives (Baher & Westerman, 2009). This idea could be transferred to a 3D art application like Tilt Brush, to compare the usability for users that are novices that may want to just have fun painting with a novel application and to users that are artists that may want to use Tilt Brush as a tool to use their skills and express an artistic idea.

CavePainting, a 3D painting application used in a Cave VR environment was praised by artists for its intuitive interface and the novel artwork it could create (Keefe et al., 2001). This suggests that there is value in applications that allow for the creation of paintings in 3D space. If professional artists see value and potential in working in this medium to create art, then there are likely further artistic possibilities that could be explored.

VR Usability Evaluations

Principles for evaluating virtual environments are still not as established as principles for evaluating traditional user interfaces, and as such many of the principles used for evaluating virtual environments borrow from more established literature. (Samini, & Palmerius, 2017). Traditional heuristic and cognitive walkthrough methods do not account for aspects unique to 3D environments, such as navigation (Sutcliffe, & Kaur, 2000).

Common measures for evaluating VR usability are completion time, accuracy, and success rate (Samini & Palmerius, 2017). In an assessment of the 2D art program Photoshop, quality of work and time to complete were used as usability metrics (Baher & Westerman, 2009). These metrics may not be as useful in this study, since the creation of painting is not necessarily a task that is better completed quickly.

Bowman et al. (2002) give a comprehensive overview of issues that make it difficult to evaluate VR usability. Relevant issues include difficulty recording users interacting with VR interfaces, evaluators making it harder for participants to experience presence in the app as intended, lack of established evaluation methods for VR, and the evolving nature of the field makes it hard for results to stay relevant (Bowman et al., 2002).

Bowman et al. (2002, p.410) describe several usability methods used to evaluate virtual environments, including formative evaluations, which they describe as "an observational, empirical evaluation method that assesses user interaction by iteratively placing representative users in task-based scenarios in order to identify usability problems, as well as to assess the design's ability to support user exploration, learning, and task performance." Sutcliffe & Gault (2004) created usability heuristics for VR applications and found that they were effective through testing them.

A study comparing usability methods (logged data, questionnaire, interview, and verbal protocol analysis) found that verbal protocol analysis was the most efficient method to use to find usability issues (Henderson, Smith, Podd, & Varela-Alvarez, 1995). Henderson et al. (1995) also described an interview protocol where subjects were asked questions about their approach to the tasks they were assigned, problems they

experienced, and suggestions they had for improving the experience. This data was analyzed using content analysis. The advantages of usability interviews are that they are a technique participants are familiar with and the face-to-face nature of interviews allows the interviewer to gather more information, especially with the ability to ask follow-up questions (Harvey, Stanton, & Young, 2014; Stanton, Hedge, Brookhuis, Salas, & Hendrick, 2004).

Interviews applied to usability studies are found to have issues with having reliability and validity as a method (Harvey et al., 2014; Stanton et al., 2004). While there advantages in using interviews to collect data on usability, it seems that augmenting that data with another method would strengthen the results of this study. The System Usability Scale (SUS) is a method that evaluates the overall usability of a system with a single score (Bangor, Kortum, & Miller, 2008). The SUS has been proven to have reliability and validity as a method ("System Usability Scale", 2013). SUS has also been used to evaluate the overall usability VR systems (Webster, & Dues Jr, 2017).

Methods

Design

In order to conduct a usability study on Tilt Brush, a combination of methods were used: observing user behavior, interviewing users about their experiences, and administering a questionnaire. The interview questions were designed to gather qualitative impressions about the interface, while the questionnaire captured demographic data and gave participants a version of the System Usability Scale (SUS) modified for Tilt Brush to measure the overall usability of the app.

The study focused on the experience users had creating something with Tilt Brush and identifying usability issues with the app. Participants were given time to test out the interface, before moving on to the main task of creating a virtual painting. Three methods to collect data for this study. Observation was the first method. While participants created their paintings, the experimenter observed them as they used the app, and took notes on their behaviors.

The next method used was a semi-structured interview. After they created their painting, participants were asked interview questions about the experience as a whole. The interview questions can be found in the Appendix. The aim of the interview questions was to get a sense of how users experienced the application and creating a VR painting. White & Marsh (2006) describe a method qualitative content analysis. Coding can be done by looking for the bigger picture that emerges from the data, identifying

themes and patterns found within the data, which in turn can be used to analyze it and drawn conclusions. This type of content analysis is the method that was used to analyze the interview data.

The final method used was a questionnaire. The questionnaire can be found in the Appendix. After the interview each participant was given a survey with the 10 questions from the SUS to measure the usability of the system. As this method is widely accepted in the usability field as a good measure of a system's usability, it will offer quantitative data on the overall usability of Tilt Brush as a system. The questionnaire also collected demographic data (gender, race, and ethnicity).

After the data was collected, it was analyzed to identify what factors contribute to the usability of Tilt Brush, what factors contribute to the usability issues of Tilt Brush, and what factors affected the creative experience of Tilt Brush.

Participants

This study sampled 20 participants from graduate and undergraduate students at the University of North Carolina-Chapel Hill. Participants for this study were recruited through email listservs, fliers, and emails to studio art classes. The call for the study asked for participants with formal training in art and participants without formal training in art. "Formal training" was first and foremost a self-identified descriptor that participants could claim for themselves or not. When asked what was meant by formal training, potential participants were given the following definition: someone that has completed an art class of some kind and feels confident in their understanding of art fundamentals and ability to create art. Participants unsure of which group to identify with

could choose either group using that definition as a guide. This allowed comparisons to be drawn between the experiences of the two groups.

Most (though not all) participants in the sample had little VR experience, and it was the first time some had tried VR. The sample included novices, testing the learnability and intuitiveness of the Tilt Brush and VR conventions for first time users.

Materials

The study was conducted in a virtual reality lab. The lab had a VR area taped off to show the settings the area was configured for. An HTC Vive was used as the HMD to run Tilt Brush. A large monitor was set up so that the PI could view what the participants were painting in Tilt Brush. A laptop was used to take notes and administer the questionnaire to participants. A Zoom H1n recorder was used to record the audio of the interviews. All participants were given a $10 gift card upon successful completion of the study.

Procedures

Participants were given a brief overview of the study before starting. The experimenter showed them how to wear the Vive and adjust it. After the participant had the Vive on, the participant was handed the controllers and told select the "Create New Sketch" option from the Tilt Brush interface. Participants were given instructions on how to do this if they needed help.

After starting a new sketch, participants were given five minutes to familiarize themselves with the Tilt Brush interface and try out whatever options they wanted to within beginner mode. A timer was set and the participant was free to do whatever they wanted. Notes were taken on how they used the app.

After the timer ran out, the timer was reset, and participants were told that they could create whatever they wanted in a twenty minute time period. The participants were asked if they had any questions and told to verbally confirm when they were ready to start. The timer was started, and PI took notes while the participant painted.

After the twenty minutes ended, the participant was asked to remove the headset. They were then given the interview questions. Finally, the questionnaire was administered. The full study script can be viewed in the Appendix.

Results

The data collected from this study provided insights into the usability of Tilt Brush. This section provides describes the data gathered about the participant's thoughts and experiences as it relates to each research question.

Participant Demographics and Artistic Training

The participants were recruited from students at the University of North Carolina-Chapel Hill. Three participants identified male, 15 participants identified female, and 2 participants identified with other genders. Six participants described themselves as Asian, two participants described themselves as Black or African American, and twelve participants described themselves as White. One participant said they were of Hispanic, Latino, or Spanish Origin.

Two groups of participants were recruited: participants without formal training in art, and participants with formal training in art. Six participants without formal training in art did not consider either traditional or digital painting a hobby. Four participants without formal training expressed that they considered some type of art a hobby or that they enjoyed some type of artistic activity.

The participants with formal training had a wide range of experience. Three participants had some type of art degree. Five participants had taken or were taking a university level art class. Three participants described art experience from classes in high

school/other sources. (Note that one participant described getting an art degree and taking an art class in high school.)

In the formally trained group, two participants did not consider either digital or traditional painting a hobby. One participant specified that they did not consider painting a hobby but considered other types of art a hobby. Four participants specified traditional painting as a hobby (three in the formally trained group), and three participants (all in the formally trained group) considered both traditional and digital painting a hobby.

Research Question 1: Factors Contributing to Usability

Users expressed positive sentiments about their experience using Tilt Brush. Several themes emerged from the interviews that described the positive aspects of usability for Tilt Brush.

Intuitive. When asked about their experience of learning how to use the Tilt Brush Interface, 8 participants expressed that they had little difficulty with it. Four participants specifically used the word "intuitive" to describe their experience with the controllers and the interface during the interviews. One participant from the group with formal training expressed that the features they found in Tilt Brush (color picker, brushes, undo, and eraser) were "pretty typical" of painting applications. For example, one participant described their experience of learning to use the interface as so: "But for the most part it was pretty easy to pick up, it was very intuitive."

When asked about the experience of learning to use the Tilt Brush interface, various factors came up for individuals that made it a positive experience for them. One participant mentioned that they were so excited to try out the different brushes, they did not notice the arrows that would take them to more pages of brushes at first. Another

participant mentioned that they found trying the brushes to be interesting. That same participant (in the not formally trained group) liked the color picker, because it was easy to understand as someone without an art background. One participant specifically describe the controllers and their interface as intuitive: "I think some things are more intuitive than the others, so I think the of the controller's menu and the other is a paintbrush or eraser that's kind of cool, and I like how I can rotate the controller for the three different menus." Two participants found the interface easy to use in spite of any difficulties they had.

      Navigation. The way Tilt Brush allows users to navigate the virtual environment contributes to the usability of the application. One theme that emerged from the interview was that overall, several of the users felt fine navigating the virtual environment. Fourteen participants expressed that they did not have difficulties navigating around the painting. There were a few caveats, but overall the experience was fine. Six participants expressed that walking around the environment was an easy experience with few problems. For instance, one participant said: "It was, it seemed normal, like you're in reality reality, not virtual…" This described an experience of feeling presence in Tilt Brush.

      The 3D perspective of the artwork allowed users to walk around and view their artwork. Users expressed that it was helpful or enjoyable to navigate around the space and see the different angles of their piece. The experimenter observed participants looking at their artwork from different angles as they worked on their paintings. Two participants expressed that walking allowed them to see their artwork from different perspectives.

Three participants expressed that the boundaries within the app helped them navigate the environment, because they gave an indication of where the real world boundaries of VR area in the lab were. (Thought one participant assumed this, but did not know for sure.) And it seemed like, I'm not sure if this was actually true, when I put my hand down it showed me the parameters of the space, and so I felt pretty comfortable.

Some participants preferred to remain stationary while painting. One participant preferred sitting down while working on their painting, saying: "but also I felt like... it just felt easier to sit down and be closer to the work." One participant did not feel the need to walk, since they could draw anywhere, including in front of themself, saying: "but I didn't feel the need to walk around that much, just because everything that could be drawn could be drawn right in front of my face."

One participant mentioned that teleporting helped them move around the painting when asked if there was anything they wanted to do in the painting but were unable to. They wanted to move more and eventually figured out that teleporting would help them do that.

Tools. The brushes offered in Tilt Brush contributed to the usability of the application. Several participants remarked on how much they enjoyed the effects they could choose from. One of the participants from the group without formal training remarked that they felt like the effects made their drawing look better. One participants mentioned that they found the color picker easy to use for someone without formal training.

Practice. One recurring theme in the interviews was that using Tilt Brush got easier for participants to use over the course of the experiment. Four participants

mentioned that they needed time to get used to the VR environment, but eventually felt more comfortable. For instance, one participant said: "...but then it feels like after awhile you're just used to being in it so you walk around more freely. " Seven participants described that they were able to get a better understanding of the interface after they had a chance to test it out over time in the study. One of these participants said: "once I figured out what each thing did, like what each, button and thing on the controller did, it was easier to navigate and figure out what everything was about." Two participants mentioned that it got easier to use Tilt Brush's functions when asked what the most difficult thing about learning the interface was for them.

3D. The 3D aspect of Tilt Brush was noteworthy to participants. Participants described how they enjoyed walking around the artwork they created and viewing it from different angles. Two more participants mentioned that walking around the environment allowed them to get a different perspective on their artwork.

Four participants mentioned that the 3D aspect of Tilt Brush was something they enjoyed the most about the application, one participant going as far as to say that it was easy to paint in 3D, especially in comparison to a 3D artform like sculpture.

One participant mentioned that they felt like it was easier to create art in 3D, saying: "The fact that it's in 3D and it's generally quite easy to paint. Like with traditional sculpture to do something like that takes much longer time"

Environment. One participant mentioned that the felt the environment was about the right size for this application: "I felt like it was enough space to walk around and create art. I think it could have been overwhelming to have a lot more space." Another participant mentioned that they enjoyed the amount of space they had to work with in Tilt

Brush. Two participants mentioned that painting in 3D offers more space than painting in 2D.

        Satisfaction with the Overall Usability. Three participants expressed that they were able to do almost everything they wanted to with Tilt Brush. The experiences with Tilt Brush described above show the positive factors that impacted the usability of Tilt Brush. The system usability scale results overall corroborate this. The results of the questionnaire yielded an average SUS score of 72.9. The group without formal training gave an average score of 71.8 and the group with formal training gave an average score of 74.0.

Participant	SUS Score
P1	70
P2	82.5
P3	77.5
P4	72.5
P5	65
P6	67.5
P7	85
P8	70
P9	55
P10	72.5
P11	67.5
P12	87.5
P13	65
P14	82.5
P15	75
P16	60
P17	75
P18	67.5
P19	77.5
P20	82.5

Table 1

Research Question 2: Factors Contributing to Usability Issues

Several themes emerged that showed usability issues that could be found within Tilt Brush. While using the app was a positive experience overall for the participants, there were still aspects of the experience that could have been improved.

Tools. One theme that emerged from the interview was that there were certain tools that would be desirable to implement in Tilt Brush, and that there were also tools that already existed that could have been implemented better. Seven participants mentioned that it took them time to find and learn how to use the tools that they were looking for.

Quotes from participants about tools
"There were some tools I wished I had learned earlier on, like the diamond tool and the I forgot what they were called, the different ones that allow you to create shapes, 3 dimensional shapes, that would have been useful. But I felt like it was very straightforward and easy to understand."
"Well first it took me a long time to learn how to use the brush and change from different types. As you probably saw I kept changing back and forth between, they had a lightsaber or something, some weird random things that I wouldn't normally associate with painting. That, so the learnable part was the biggest challenge for me."
"Yeah, and some buttons were harder to find than others. I was trying to find the basic brushes of the fancy stars and snows and stuff, and then took me quite a while to realize that the paint brush menu has a left and right button so there are more choices."

Table 2

These quotes provide examples of the sorts of tools that were not immediately obvious to participants. Learning the functions of the brushes provided a challenge to users.

One participant mentioned that while they liked that the brush names were labelled, the labels themselves went against their expectations: "And then I would say that I liked, I think that when you hovered over it, it said what it was. I don't necessarily know if I thought all of those descriptions were the best, because when I expected one thing when I would paint and it was a different thing, so that was interesting too." One participant mentioned that they did not realize there were multiple pages of brushes to scroll through. One participant expressed that having to test the tools out before they knew what they did was the hardest part of using the Tilt Brush interface: "I think maybe having to test everything before I really knew what it was, potentially was the hardest part." Four participants found that finding and figuring out the different brush options (how to readjust brush size, what each brush actually did, finding the kind of brush they wanted, etc.) was the most difficult part of using the Tilt Brush interface.

One participant wanted the tools to give them more control to fine-tune their artwork: "But other than that the thing that I found most difficult was sort of fine tuning things or a fine point brush. I know you can make the brush bigger or smaller depending on what your preference is. But the brush seems to work when you move it around, whereas it would have been really cool to do something like where you could press the trigger and move it back and forth like this to get dots or be able to use some sort of a pencil to sketch something out or to be able to more fine tuning of something." One participant wanted more brushes that were closer to the kinds of brushes found in traditional painting. One participant wanted a curved line tool. One participant from the formally trained group repeated stated their desire for a blending tool. One participant wanted more control over their lines.

One participant wanted to see the ability to sculpt a "clay slab" in Tilt Brush: "Also I could picture real life artists using this, maybe sculptors so it could see it maybe being you could start out with a big slab or like a cube of like clay that's in the middle and being able to carve away at it, that would be really interesting"

Eraser/Undo Button.

One participant had trouble figuring out how the eraser worked. They had trouble finding the undo button: "I think understanding how the eraser worked was a little bit hard. When I tried to erase things, also it took me awhile to realize there was an undo button, which in all digital drawing there is an undo button, so I should have guessed there was one sooner. So I was erasing when I could have just pushed undo originally." One participant mentioned using the eraser as something they wanted to do in their painting but were unable to: "I'm not sure if it was me, but erasing, erasing. I was trying to erase the head, but it wouldn't, but it had an X, so I guess it wouldn't let me. I guess it had to be a recent drawing, I'm not sure." One participant mentioned having trouble finding the undo button.

Color Picker. One participant with no formal training mentioned wanting pre-set colors in their interview responses. Two participants mentioned having trouble using the color picker to select the precise color that they wanted to use in their artwork. This quote from one of the participant's interviews describes the issue: " But there was one point that stood out to me where I was trying to get the exact shade of teal that I wanted and I couldn't drag that color picker to where I wanted it to be and that was very frustrating."

Another difficulty noted by two participants was an inability to reuse the same color once it had been switched. It was very difficult, if not impossible to get a match a

previously used color. The tool for accomplishing this was not available in beginner mode.

The observation data showed that only 5 participants found the color palette, and it was questionable if some of them understood how to use it, or wanted to use it. All other participants just used the color picker to approximate similar colors or picked completely new colors entirely when working on their paintings.

Straightedge. One problem that several participants experienced was not realizing they had selected the straightedge option. Most of them, except for one, were able to find the straightedge option eventually and turn it off. One participant asked the experimenter for help; the experimenter prompted them to look through the options again, and they were able to find the straightedge without being given explicit instructions.

One participant said that accidentally having the straightedge accidentally on was the most difficult part of using the interface: "What I found most difficult was when I didn't realize what mode I was on. I had accidentally clicked the straightedge mode and I didn't realize it. I was wondering why all of the brushes were so straight. It felt like that limited me. So, I finally realized it must be a mode, but it wasn't on the screen with the other paintbrushes. So, I had to ask you for help and you said to look around for that. So that was one of the most challenging parts too."

One participant did not find the straightedge at all, and it affected the experience they had using Tilt Brush, as can be seen in this quote: "The biggest thing that I ran into was probably the fact that you couldn't, maybe, like I said maybe you can create curved lines, but I did not figure out how to create curved lines. So I would be used to making

certain brush marks, I would make a circle or make an oval, but I would forget to hit the clicker thing, so I would just make one long, straight line, so definitely very different than regular painting."

Brush Size. Two participants mentioned that they were unable to change the size of the brushes they were using. Both of those participants listed being unable to change the brush size as one of the most difficult aspects of using the Tilt Brush interface. One of these participants changed the brush size by accident, but was unable to figure out how they had done that and could not change it back or make any adjustments to the size.

Select and Move. Two participants expressed that they wished they had the ability to select their artwork and move it to a different location in the painting. This is a feature available in Tilt Brush, but not in beginner mode.

3D. The 3D environment was strange for participants to enter into. Three participants expressed some degree of difficulty conceptualizing or adjusting to the 3D space. One of these participants described it like this: "I forgot that you could walk around since it is virtual reality, so I made it a very one sided painting and then realized that I had the whole other side to still use so it took me time to understand that mindset of it all."

Two participants mentioned that they had expected the painting to be 2D. The ability to use the entire environment for the painting was not what they expected. One participant described their expectations: "I guess obviously I didn't realize that the entire thing was already a canvas. I was kinda expecting like a white something to pop up. "Two participants mentioned that they didn't realize the environment would be 3D. One of those participants described an experience that illustrates that point: "At first, when

standing still there and facing... The first environment I choose is a snowman, and there is

a 3D snowman in front of me. At first I didn't realize that "Oh this is actually 3D and this

is virtual reality." And when holding the brush, I was still feeling like I'm painting on a

flat canvas…" One participant mentioned difficulty perceiving depth as a difficulty of

navigating the painting: "Yes. I think the biggest thing I was having was, even though

there was a grid on the outside, there wasn't necessarily a grid... I guess that would be

what? your z-space kinda thing. So, you think you would be getting close, but in reality it

would put you way far away. So I think that way my, I didn't feel like there was any

depth of field, and maybe that was just being in the white background, and then I went in

the black background"

Five participants mentioned that going from thinking about creating art in 2D

space to creating art in 3D space was the most difficult part about using Tilt Brush's

interface. These two quotes illustrate that difficulty:

> "I think it was just because you're in a 3 dimension or 4 dimensional space (I
> don't really know). You have to figure out how to use the tools to figure out how
> to create three dimensional objects while you're in the space or else it looks kinda
> funny like you made this flat thing. So it was difficult figuring out how to, first
> when I didn't know you could make the whole figures. And I was trying to make
> cylinders using the ribbons and I was just having to go around and around around
> with my hand. Or make cubes like how you would draw them on paper with a
> pencil. So that was probably the hardest part about it."

> "So actually, I never did 3D painting before. So the most difficult thing for me is
> to transport from 2D painting to 3D painting. So actually I am painting my high
> school, but I feel difficult when I need to. For example, I tend to draw a tree, but I
> don't know how to draw a 3D tree. So you saw me that I more likely to do 2D
> painting then connect 2D together."

One participant found that working with the third dimension was more difficult

than painting in 2D: "Painting in 3D it takes a lot more work, again because it's that

volume component. You're not painting one side of what you're seeing, you're painting

all sides. And your painting with depth too, so it is simply more intensive, but I think it's worth it." One participant felt like they had less control in 3D than in 2D. Another participant noted that it was harder to fine tune artwork in Tilt Brush: "But I also think that, one of the things I was thinking about while I was in the environment was it would be almost impossible to recreate 2D objects in a 3D environment and do it well. So I don't see it as the kind of environment to make the next Mona Lisa. Like it's not gonna be a place that you go into and that you create with all the fine-tuning, the brush strokes, the things like that." One participant mentioned that painting in 3D was time-consuming.

Two participants cited a lack of familiarity with 3D something that made it more difficult than painting in 2D.One of them provided an example: "Oh, can I add, a new point, so I feel like for me it's hard for me to transport from 2D to 3D. So, for example, I want to paint a building, so I don't know if my painting really constructs to a 3D structure. I don't know if it really looks like a building and for example, I draw straight lines, but I didn't know if they are constructed to like a square. So I think that the hardest point for me."

3D Shapes. One desired feature was the ability to create 3D shapes. Not every participants was aware of the diamond and hull options. Some participants mentioned shapes that were not available in Tilt Brush, such as cylinders and spheres.

One participant mentioned the lack of ability to create 3D shapes as the most difficult part of using the Tilt Brush interface: "I think creating three dimensional shapes, so trying to create a globe or a structure. And I wasn't sure, I kept thinking there must be some way to make shapes that I just don't know. There must be a sphere button or a

rectangular prism button or something. But I was able to make do with some of the paint materials."

Navigation. One participant expressed that the reason they did not move much was because they had trouble seeing the virtual environment for creating art as a 3D space: "Well, I'll be honest I stayed in one place most of the time. Like I said, getting around the idea that it's a 3D space and I was trying to create 2D art was difficult."

Another participant wished that they had started their artwork in a different location in the VR space, because they felt like they were limited by the space constraints where they made their VR art: "I wish I started somewhere over here so that I have more space."

Several participants expressed anxiety about being in the VR environment. Participants expressed anxieties about going outside the borders of the VR area, running into the PI who was observing, and running into the walls.

One participant expressed fear when changing the environment options. They felt afraid of the space environment because it did not have boundaries. Four participants expressed that it took them some time to get used to navigating VR and feel more comfortable in the environment. As mentioned previously, one participant thought that the grid boundaries corresponded to the real life VR area, but they were not entirely sure that was the case. Two participants mentioned that a lack of awareness of the real environment posed an obstacle to navigating around the painting. One participant mentioned that they still were not used to the virtual environment of Tilt Brush, even though they did enjoy themselves. One participant mentioned that being immersed in VR

was something they needed to get used to: "I've never done anything in a virtual lab before. So getting acclimated to not seeing what's around you is kinda weird at first."

Moving Through Art. Participants expressed that they were worried about running into the artwork they were creating or felt weird about going through it. Three participants mentioned moving through the art (or avoiding moving through the art) as part of the experience of walking around the virtual environment.

Three participants expressed that feeling like they had to avoid the parts of the painting they created was a difficulty they had in navigating the painting. These quotes illustrate how participants experienced this:

> "I remember I started out walking around it, and then I realized I could just put my hand through it, but the fact that I thought it was something made me not want to put my hand through it, so that was interesting when I was trying to create a 3D effect. I was afraid to punch my hand through the 3D tree for example, cause I was like "No, it's a tree; it's there!" So that was interesting."

> "...again it felt weird walking through your artwork, cause I felt I would mess it up if I put my head through what I drew…"

The artwork was perceived as actually being a real object in the environment. Moving through it was an odd experience for participants because it seemed like a real object to them.

Controller Menus. One participant had difficulty scrolling through the menus: "The scrolling thing to get through the different menus, that was a little difficult, but not getting through the painting itself."

Four participants noted that using the controllers to go through the menus and select options was the most difficult part of using the interface. Two of those participants described their issues with this way of interfacing:

"Definitely the controller. Since it was like in a circle I was expecting it to go around with my thumb, but then I looked at the arrows and like you just have to go from side to side. So when I was having trouble I couldn't figure out how to look at all the color, the types of brushes, all that... And then I didn't figure out that you could change the size of the ink or whatever with the controller until halfway through."

"...the edit/undo button was a little bit of a hassle, because I'm used to just pressing control-z edit-undo when you're typing on a graphical user interface, versus here you have to hold up your paint brush, tilt you hand to the right menu, press undo again with your other hand and then you can get back to painting. So that was more cost into the time it took to undo something that I hadn't anticipated."

Teleportation. Teleportation was only used by 10 participants. It posed several challenges for those who used it. One of these participants went as far as to say that teleporting was the most difficult part of using the interface. Three participants used the teleportation feature but did not understand what it meant. One of those participants was under the impression that the teleport feature cleared their painting. They tried it out, expecting the shoes icon to mean that a pair of shoes could be added to the painting, but instead were teleported away from the painting they had been working on.

Two participants found the experience of teleporting disorienting, but not impermissibly so. One described that experience like this: "It was a little bit disorienting when you would go there and then you would be obviously facing the wrong direction so you have to flip around, but I don't know how else you would do that. But it was relatively simple to understand, as long as you're going within the boundaries."

Two participants found it difficult to gauge the distance they would teleport in the virtual environment; they were unsure where they would end up. One of those participants preferred to take smaller steps instead of teleporting, showing a discomfort with navigating the VR environment in general.

One participant was scared by an experience with the teleportation feature. They were in the dress form environment and wanted to get closer to the dress, but teleported into it instead: "It's really terrifying, especially when I had the dress form, and I was trying to move the dress form closer to me, and it was right on me at some point, and that was scary." That participant expressed that if they had an opportunity to further practice teleporting, it may become less "scary" for them.

One participant said that it was difficult to use the teleport feature for traveling small distances. One participant expressed that they found it difficult to get back to where they were prior to teleporting: "And then trying to get, which I know there was an undo button, but I completely forgot to use that. Trying to get back to where you were to then maybe try again. Yeah, like I was saying earlier, I felt like I would end up randomly in the middle of the painting and then not know how to get back."

One participant didn't use the teleport feature much because they thought it was a different game.

HMD Issues. The design of the HMD posed usability issues for participants. Several participants expressed nervousness with using VR. Some participants had trouble putting the headset on because the strap did not fit over their hair.

Three participants mentioned being nervous about tripping over the cord.

This quote shows that a participant was too nervous to fully take advantage of the ability to walk around in Tilt Brush: I didn't walk around that much, partially because I was scared I was going to trip on that cord.

The controller menu also posed some difficulties for users. 8 participants did not realize that the trackpad could be used to rotate the controller's menu, instead physically

rotating the controller menu in their hand. This motion could be awkward and was less smooth than rotating through the menu the other way.

Four participants also stated that using the controllers to navigate the menu was the most difficult part of using the interface to create their painting. One participant pointed out how difficult undo in this program was compared to a typical 2D painting program: "The edit/undo button was a little bit of a hassle, because I'm used to just pressing control-z edit-undo when you're typing on a graphical user interface, versus here you have to hold up your paint brush, tilt you hand to the right menu, press undo again with your other hand and then you can get back to painting. So that was more cost into the time it took to undo something that I hadn't anticipated."

Participants had trouble figuring out how to use the full functionality of the controllers. It also did not respond in the way they expected it to. Two participants expressed that using the controllers was a difficult part of learning how to use the Tilt Brush Interface.

One participant described that it was weird to be fully immersed in the virtual environment: "I've never done anything in a virtual lab before. So getting acclimated to not seeing what's around you is kinda weird at first."

Two participants specifically mentioned the cord as a difficulty navigating the virtual environment.

One participant mentioned that the view of Tilt Brush would get blurry depending on the positioning of their head: "Sometimes trying to move your head to see the entire menu would kinda screw up the blurry/clear focus of the rest of it. So I would kinda feel like I was trying to look at the entire screen but then it would get blurry. But then I have

whatever is better than 20/20, so that's not a common thing for me. So I was like 'Oh, what do I do with this?'"

One participant mentioned that painting in 3D could be difficult because they had to stand up.

Research Question 3: Differences Based on Artistic Experience

Part of the design of this study was comparing a group of people with formal training in art to people that had no formal training in art. These two groups could be compared for similarities and differences in the way they used Tilt Brush and interacted with the interface.

Differences Between Participants with Formal Training and Participants without Formal Training. Six participants pointed out that depth already exists in the environment, and only one of those six was from the group without formal training. This quote illustrates how a participant with formal training described that:

"Well, there's automatic depth that you're now creating on your own. I think you would create depth with more shadow and line, just standard art things. With this you just create depth by moving in a certain way with the tool, and also it already has depth because it's in 3D. I think for someone who may is used to... It's a different game, cause you're not shadowing and you're not blending, you're trying to figure out how to use the tools to do that, and I think that that's interesting."

It seems that the formally trained group is more aware of the depth that exists in the environment and the implications of being able to use that third dimension. This can also be corroborated by the observation data. Participants in the group with formal training tended to pay more attention to the details and construction of their artwork. Five

participants in the group without formal training expressed that thinking in 3D was difficult or different from what they were used to when asked to describe their experience learning how to use the interface.

As previously discussed, the experiences brought into this study differed between the two groups. As one would assume, the group with formal training could relate their experiences back to their understanding of artistic concepts.

One participant in the formally trained group mentioned that Tilt Brush's interface was similar to 2D painting applications they had used prior. "It was interesting. [The] interface is pretty typical of the painting applications that I've used. It's got the color picker and then the brush-set, and then the kind of more interface-y things like undo and eraser and there's some environment stuff I'm not sure I completely understand, which is generally how it goes when you're first learning how to use a new program. So even with the VR component, I think it was pretty typical." This was not experience anyone in the group without formal training described.

Experience. Both groups reported enjoying the experience of Tilt Brush, and expressed that they would be interested in using that app again. Both groups also felt that they were able to express themselves with Tilt Brush, though two participants in the group without formal training mentioned that their lack of artistic ability was a limiting factor. Overall, both groups had a positive experience with Tilt Brush. They enjoyed aspects like the immersion, the tools available, and the fun they could have creating artwork in this particular environment. Both groups also experienced similar challenges; very few themes described seemed exclusively limited to one group or the other.

Research Question 4: Enjoyment of the Artistic Experience

All 20 participants in this study stated that they enjoyed the experience and expressed interest in using the app again. Of the 20 participants, 18 said that they were able to express themselves, and the other two expressed that they expressed themselves as best they could with limited artistic ability. While there were a few caveats, the prevailing sentiment was that using Tilt Brush was an enjoyable experience. Several themes emerged around what made Tilt Brush an enjoyable experience.

Immersion. Immersion was mentioned by seven participants as what they enjoyed most of the experience. The options for the environment contributed to a feeling of being immersed in virtual world. The ability to be "in" the art and for participants to create it around themselves also contributed to feelings of immersion. A couple participants described this:

> "I think the thing I like the most was the visual scenery when you change the environment from like space to like the pedestal to the standard one and then drawing on top of that makes you feel like I'm actually in outer space and you just look at a white paper when you're drawing normally so it was kinda cool."

> "I think being immersed in the painting. Being completely surrounded, it was so different. It's not like theater where you have to build a set around you piece by piece to create this feeling of being somewhere different. It was really cool to just be able to you know, move your hand and all of a sudden your environment has changed. It was really kinda, I don't know, it felt kinda like magic."

Two participants described their experience of walking around the environment as being immersive. When asked why they would use Tilt Brush again, four participants touched upon the immersive capability of the app as a reason why they would return to it. One participant described why they enjoyed it: "...it's a fun way to get out of real life."

Two participants cited immersion as a factor that made painting in 3D different from painting in 2D. One of those participants said: "The fact that it was 3D it was so big and so immediate. It was so interactive, whereas anytime you're using a screen, you're automatically removed it's something apart from you that you're interacting with and you're still influencing it, but to be immersed in it is a totally different experience."

Two participants cited the environment they were painting in as a factor that helped them express themselves. One of those participants said: "And then I do like how the backgrounds quote-unquote, intimate this big vista you've got, so it appears you've got all this space. So that makes you feel kinda free and open."

Novelty. Novelty also emerged as a factor that contributed to participant enjoyment of Tilt Brush. Six participants indicated that the experience was novel for them in some way. It was a new experience that allowed participants to try and learn a different art form.

One participant mentioned that getting to use the "VR model" was their favorite part of the experience. Two participants mentioned that getting to do engage in a new type of artwork was the most enjoyable aspect of Tilt Brush to them. One participant mentioned that Tilt Brush allowed them to try new things when asked why they would use the app again. One participant called Tilt Brush a "novelty". When asked if they were able to express themself, one participant said that Tilt Brush offered an opportunity to try something new: "But that's cool though, it's an opportunity to learn something different instead of doing the same things. But I had a different idea about what it, how you'd be able to do it I guess. It's not just like painting, because things are flashing... there's bubbles. So the tools aren't just different size brushes or something."

Tools. Two participants mentioned the different tools available in Tilt Brush as an aspect of the app that they enjoyed. One participant described that as something they specifically tried to do: "It was really exciting to use all the different tools. The mission of my painting was to use every different type of brush that I could because they were all very fun and unique and I really enjoyed them"

When asked if they were able to express themselves in Tilt Brush, eight participants mentioned that the tools available to them helped them create what they wanted. One participant described it like this: "I really enjoyed just all the different colors and tools and yeah, all the different ways where you could really just create anything."

Brushes. Four participants mentioned that the brushes available to them were what they enjoyed most about the experience. The effects they created were fun and interesting. This participant comment illustrates why they enjoyed them: "I enjoyed seeing all the different things that you could create in virtual reality. I really enjoyed the special effects they included in the game like the bubbles and the smoke and the stars and the snow and I really enjoyed seeing those elements come to life. And enjoyed some of them kinda surprised me, there was one, I forget the what name was, it was like the neon color or neon light, so it changed colors. It was just exciting to see what each different thing could do."

One participant mentioned that it was nice that Tilt Brush was less messy than regular painting (with the caveat that they missed the smell of paint).

3D. Participants enjoyed the 3D nature of tilt brush. Four participants mentioned that it was the 3D aspects of creating art with Tilt Brush that they enjoyed the most. Here is an example: "I think just being able to experiment with like depth and being able to

like wrap things around other things and like to make lines like interconnect and like loop around each other. I thought that was really cool"

One participant specifically mentioned the ease of 3D as being something they enjoyed while using Tilt Brush: "The fact that it's in 3D and it's generally quite easy to paint. Like with traditional sculpture to do something like that takes much longer time." One participant stated that they knew right away that they wanted to use Tilt Brush for it's 3D capabilities when creating their artwork: "I think immediately I knew I wanted to do something in three dimensions instead of just try to paint some 2 dimensional form." Three participants mentioned that they enjoyed the 3D perspective when asked how their experience was walking around the environment. One participant said that they would use Tilt Brush again specifically because it provided 3D capabilities "...and again because of the three dimensional. Don't get me wrong, I love painting in the way I do. And like I said I definitely am more of a traditional media sort of person, and I get used to working in a certain mindset and just the concept. The biggest kick I got out of this was being able to lay down color and then physically walk around it and then work behind it. That was a blast!"

One participant cited being able to draw wherever they wanted as a reason to use Tilt Brush again: "Another reason I would like it would be because you can stand up and draw where ever you want…"

Five participants pointed out that depth already exists in 3D painting in a way that it does not with 2D art. One of the participants with formal training gave a good description of this: "Well, there's automatic depth that you're now creating on your own. I think you would create depth with more shadow and line, just standard art things. With

this you just create depth by moving in a certain way with the tool, and also it already has depth because its in 3D"

When comparing 3D painting to 2D painting, two participants mentioned the unique perspective that 3D affords. An example is: "I could go behind the picture, under if I wanted to, whereas 2D is pretty limited to the page itself."

One participant noted that in Tilt Brush, users had the choice of making artwork that was 2D in the 3D environment or they could choose to make artwork that was 3D: "You definitely I think need to make a choice of what kind of thing you want to make. Whether it is a 2D appearing item or a 3D appearing item, so that's different, making those choices."

Four participants mentioned that they were able to express themselves using Tilt Brush, but it was not in the way that they expected. One described that like this: "When I was thinking about making a painting or drawing at all, I was thinking I would do it in a style that I normally use, but I just couldn't get a handle on what that would look like in a 3D space."

One participant was really interested in the potential of a 3D environment for self-expression: "Yeah, I think if you had more time to really toy around with it, you could make really interesting compositions. Like if you made something and your viewer was able to enter it, then that gives them like a 3D space to sort of explore what you're trying to say, whereas like even in sculpture you're viewing a 3 dimensional thing whereas this you're in that space."

Navigation. Two participants mentioned that they enjoyed walking around the virtual environment. One participant found it "interesting" that they could walk through

their painting. Two participants mentioned that specifically navigating around and through their artwork was one of the most enjoyable aspects of the experience. One participant mentioned that one thing they liked about painting in 3D was the ability to move around.

Two participants mentioned that they enjoyed teleporting, with adjectives like "fascinating" and "fun." Three participants expressed that they thought teleporting was "cool" or that they "enjoyed it" when asked about their experience teleporting around the environment. Teleportation, while overall seeming to be a feature with usability issues, did offer benefits that users mentioned in the interviews. It was an enjoyable experience for some users that offered the ability to shift their perspective of their art and to provide the option of working on a project bigger than the confines of the VR area.

Easy. Two participants mentioned that they would use Tilt Brush again because it was an easy app to create with.

VR Accessibility. When asked about whether they would use the app again or how much they enjoyed the experience, six participants brought up caveats that came along with the VR environment, showing how perception of VR affects the participant's ability to see themselves using this application again.

Examples of Caveats
I don't know how expensive this equipment is, but if I wasn't living in a tiny studio apartment, I would totally look into it.
I probably would, if I had a chance to
Definitely if I had access to it, then I would. Yeah, I think if I had some sort of virtual reality headset and space and then I would. I'm not sure if I would for the sake of I enjoy sharing my art. I feel like at some point enough people will have virtual reality headsets that it'll be easier to share. But at this point, I would feel less like I was sharing it.

Table 3

At this moment in time, VR is not an accessible technology for most people. Participants brought up concerns about space constraints, not having access to VR headsets like this one, and difficulty sharing the artwork they create, as the quotes above illustrate.

One participant had some specific caveats that came along with using VR. They preferred traditional artwork for their hobby, they also felt uncomfortable wearing the HMD with their glasses, and standing up for the full study was tiring for them.

Relaxing. Five participants said that they would use Tilt Brush again because it was relaxing. Here is an example of how it could be relaxing: "But I definitely think I would. It would probably be a good stress reliever, which is how I use my painting now."

Creative Outlet. Seven participants expressed that using Tilt Brush was a good creative experience for them. Six participants considered the opportunity to be a creative a reason why they enjoyed using Tilt Brush. One participant mentioned the possibilities of creating with Tilt Brush as their favorite part of the experience: "Honestly, just the idea of being able to create something. Sort of the possibilities for working within that environment. Like I said I'm not that great at art, I don't consider myself being an artist in any respect of the word. But I think that using the different tools, looking around the different environments. I really enjoyed being able to see the different possibilities for what you could create in a virtual reality environment in tilt brush." Two participants said that they felt like they could be creative when asked if they were able to express themselves with Tilt Brush. Five participants stated that being able to use Tilt Brush as a creative outlet was a reason why they would use the app again. These quotes illustrate why:

"And it reminded me of what's so fun about drawing, just going into a flow state and just making something, that was really cool."

"But I really enjoyed just the fact that I had to think creatively and do some art."

Valuable. Tilt Brush offered an experience that held value for participants. One participant considered using Tilt Brush and "eye-opening experience." This was their full quote: "Yeah, no this has been one of the better experiences of artists, I think eye-opening experiences of the past couple, past year or so, college. I think it's a very different experience." One participant said that understanding Tilt Brush felt good to them. Two participants explained that learning was the most enjoyable part of their Tilt Brush experience.

Two participants mentioned real world applications they could see Tilt Brush had potential for helping with. These were what they came up with:

"Although now that I think about it, I am active in performance art, like theater and haunted houses, so it might be kinda useful for pre-designing a room or a space or a set."

"I could imagine endless applications for this, maybe for interior designers. Maybe for people in professions like that where you have to visualize a space."

Wanted More. There was a sense that participants wanted to do more with Tilt Brush. One participant wanted more time to work on their artwork. Two participants mentioned that if they practiced more they would be able to make better artwork. Four participants said they would use Tilt Brush again specifically to continue learning about Tilt Brush and exploring the possibilities the app provides. These two quotes illustrate why:

"One, I felt like I was finally figuring out the whole 2D vs. 3D environment, I'd like to continue exploring that."

"I'd like to learn more about it. Cause I think that you could create some really unique, interesting pieces of art through the app."

One participant wanted to use the app again so they could try the audio capabilities of the app and listen to music while painting. One participant wanted to see what other people had made using Tilt Brush. One participant wanted to try and use Tilt Brush while sitting on the floor.

When asked if there was anything they wanted to do in Tilt Brush that they were unable to do, several participants expressed a desire to further explore the possibilities of the app. One participant wanted to explore sharing their art, as well as trying the video and audio options. Another participant wanted to try more of the brushes. One participant wanted to try to use more of the 3D environment. Another participant wanted to try out the space environment option and make artwork there.

Difficulties. One participant wished that there had been some kind of guidance to help them paint in 3D. Another participant found that the straightedge being on, posed some difficulty in their ability to express themself.

One participant expressed that they would use Tilt Brush again, if they had time in their schedule for it, illustrating an external difficulty potential users of Tilt Brush may have.

Overall Enjoyment. Again, all twenty of the participants said that they enjoyed using Tilt Brush. When asked to describe their experience learning how to use the Tilt Brush interface, five participants described it as enjoyable, using adjectives like "fun" and "awesome" to describe the experience. Four participants expressed that they would like to continue exploring Tilt Brush or learning how they could use the app. Four participants said that they had fun while expressing themselves with Tilt Brush.

Six participants expressed that they would use Tilt Brush again because it was a fun experience. One participant described it like this: "Cause I think it is really fun. I forgot how much fun it is to take a little bit of time for yourself, even though this isn't for myself, this is for a study." One participant mentioned that they doodled as a hobby, so Tilt Brush was an enjoyable experience for them.

One participant mentioned specifically that they did not like art, but they did enjoy the experience of Tilt Brush: "I don't usually like art, um at all. It was my least favorite class in school, but I did really enjoy that." Two participants said that painting in 3D was more fun than painting in 2D.

Discussion

Research Question 1: Factors Contributing to Usability

The results of the interviews and questionnaires offer several insights into what factors positively impact the usability of Tilt Brush.

Familiar Conventions. The interviews revealed that while Tilt Brush had usability issues, overall participants generally found it easy to use. The results from the System Usability Scale confirm this, as the scores are high. One of the reasons participants found Tilt Brush "intuitive" was the use of familiar conventions from 2Dpainting applications and interfaces. The menu interfaces were styled in a way that would be familiar from 2D painting applications. While rotating different menus via a controller may be a novel concept, having different menus to select colors, look through brush options, and to select the tools to use certainly has been done before. This gave participants reasonable expectations for what each option on the menu did. While this was not executed perfectly, with specific options on the menus posing issues for participants (discussed in the next section of this paper), it was executed well enough that participants were able enjoy using the application.

For instance, the interface of the color picker was recognizable from the advanced color selection option from many computer programs. The participant could use the controller to select the color they wanted and make adjustments to it. There were two interfaces participants could choose from to select the color they wanted. Using the controller to make that selection was certainly different from using a mouse, but the

principles were the same. Once the participant learned how to make a selection with the controller, they could apply that knowledge to a familiar interface.

Tilt Brush also had built in guidance for one of the more unfamiliar aspects of using the interface. When starting Tilt Brush, it provides guidance on how to make a selection by pointing the controller and pulling the trigger. The PI of the study also provided help explaining this for participants that were having trouble. After trying it, the participants understood how to interact with the app and make selections and eventually make brushstrokes.

Navigation Maps to Real World. The navigation of the virtual environment is an important aspect of Tilt Brush. Painting in 3D requires navigating through the space, and this can be accomplished in a variety of ways. The results of the interviews and observations showed that participants had varied ways of moving through the virtual environment. Tilt Brush had the ability to accommodate different preferences for movement. A participant could sit down or stand up, move around the whole space or not move at all, stay within the space of the VR area or teleport beyond it, and they could still make artwork no matter which choices they made.

The way the participant's movements corresponded to their movements in the real world in Tilt Brush was no doubt helpful to making participants feel comfortable while navigating the environment. When walking, the distance they moved in Tilt Brush corresponded to the distance they moved in the real world. This helped contribute to their orientation and sense of presence in the virtual environment.

The grid that appeared when the participants got close to the edge of the VR area also helped several participants feel more comfortable navigating the VR area, since it

gave them a sense of where the edge of the space that was cleared for them to move around in was. They could move freely within the boundaries without worrying about running into anything.

Usable Overall. Overall, this study provides evidence that Tilt Brush is a highly usable application. The average SUS score was 72.9, with the lowest score being 55 and the highest score being 87.5. All participants enjoyed the experience using the app, expressed some degree of interest in using the app again, and felt they were able to express themselves to some extent. The third section of this discussion looks in more detail at what factors contributed specifically to the experience of using Tilt Brush, but in regard to the usability it seems that the familiar design and the familiar navigation helped the participants get started with the app and be able to create something within the twenty minute timespan.

Research Question 2: Factors Contributing to Usability Issues

While Tilt Brush had good usability overall, it was not a perfect experience for users. The interviews and observations revealed several problems with using the application.

Lack of Control. A theme that seemed to recur in the difficulties participants described in using Tilt Brush was that the tools did not give them the degree of control over the artwork they would have liked. Some of this lack of control resulted from misunderstanding the application's functions. Some of it resulted from missing features.

Color Picker. The lack of precise control over the color picker was an issue for several participants. The two biggest issues were an inability to select a precise color and

the inability to match previously used colors, both of which pose problems for creating artwork.

Colors are primarily selected by dragging a point in the interface, in either a circle with multiple hues to choose from and a rectangle to adjust the brightness, or a square that allowed you to adjust the brightness and a rectangle to allow users to adjust the hue. Using the controller to drag the colors to a certain point was problematic because it was difficult to achieve total precision. A shaky hand could especially make it more difficult. Having only the physical option to change the color by using the controller to select the shade and hue on the interface

Tilt Brush did have the ability to save colors, but most participants did not use this feature. When a color was changed, there was no tool in Beginner Mode to retrieve it, making it difficult for participants to match a color they used previously. This was frustrating since it did not allow users to go back and make adjustments to their artwork with colors they had previously used. Advanced Mode does have a feature that can achieve this, but it was still a difficult for participants in Beginner Mode to be without it. Most of the participants did not use the feature that allowed colors to be saved in a color palette. One probable reason for this was that saving colors was a achieved by hitting a small plus icon in the bottom corner of the interface. It is likely that most participants did not notice it, or if they did, they did not understand what it meant and ignored it.

Brushes. There were also several usability issues with the brushes. Participants had trouble understanding what effect each brush created without testing them out. They also had trouble finding brushes that created the specific effects they were looking for.

Another issue some participants had was having trouble figuring out how to adjust the brush size.

The brush menu provides an icon and a name that represents each brush. This gives each participant an idea of what the brush does, but depending on their expectations based on the name or the icon, they could have expectations that differed from the reality of the function.

Adjusting the size of the brush is not necessarily an obvious feature. The size of the brush can be adjusted using the trackpad on the controller that participant is painting with. This is separate from the menu interface that participant controls most of the tools with. While guidance for adjusting the size of the brush does pop up when the user interacts with that trackpad, it may not always be obvious enough for users to notice.

Missing Features. Several participants expressed a desire for features that did not exist within Tilt Brush. This again shows a desire for more control over the artwork they are creating.

One desired feature was the ability to select artwork and move it to a different part of the environment. This would allow the composition to be altered in a way that is more in line with the artist's vision for the piece. It also mirrors selection tools that can be found in 2D painting applications. Again, this feature does exist in Advanced Mode, which perhaps would have been preferred by the participant. Another feature desired by a participant was a smudging tool. Again, this gives more control over the aesthetic of the artwork.

One of the most popular suggestions was the ability to create 3D shapes directly, instead of forming them with 2D brush strokes. This somewhat exists in Tilt Brush

already, as a few of the brushes can make 3D forms. However, there is no ability to directly place a sphere or a cylinder or triangular prism in the artwork. This creates more work for the user as they have to build these forms out of 2D lines, which can be difficult to conceptualize in 3D space. They also cannot create these forms precisely in Tilt Brush.

While a few of the existing brushes do allow for some 3D forms to exist in Tilt Brush, it relates to the earlier usability issue discussed where it was not always obvious to participants what each brush would do or what its name and icon meant. There is no indication that these brushes would create 3D forms or that they would be any different from the 2D brushes.

The desire for geometric shapes seems natural in a 3D environment. While the artwork exists in three dimensions, it makes sense that participants would want to use 3D elements to build their art pieces. It would also make it easier for the users to control the forms they are creating and create more precise shapes.

Menu Issues. The menu interface also posed usability issues. A problem that was observed multiple times was that users would turn on straightedge on accident, not realize they had it on, and get frustrated that they could only paint straight lines. Part of this issue may a lack of familiarity with the interface. Only one participant never figured out that they had the straightedge on. Another contributing factor may have been that the indication that the straightedge was turned on was not strong enough. This seemed to be the case with other tools on that menu, such as the eraser. The white highlighting was not enough for the participants to notice that the feature was "on" instead of "off."

Another issue with the menu was that the ability to scroll through them using the trackpad was not clear to all participants. Some participants physically rotated their

controllers to switch menus, which was not as smooth as using the trackpad in the virtual environment and could be an awkward physical movement to make. The lack of familiarity with the Vive's controllers may have contributed to this. It also may have been another case of this function not being obvious enough for users to notice and understand.

Another issue with the menus is that it could be tedious to perform certain actions, having to rotate the menu, point at the correct option, and pull the trigger. One participant clearly illustrated this by comparing the process to undo something in Tilt Brush to the ease of hitting ctrl+z to undo brushstrokes in 2D painting programs. Building in shortcuts for common actions could improve the usability of the application.

3D. The 3Denvironment also seemed to contribute to usability issues for users. It was clear that the third dimension went against some of the participant's expectations and it took actually using the app and experimenting with its tools to create artwork to adjust their mindset to creating with the third dimension.

Painting has an inherent 2D connotation, so it may be that this biased participant expectations toward the 2D. Painting in with a third dimension is also a novelty that most participants would not have been exposed to before. The lack of familiarity with this kind of artwork and the techniques necessary to create this kind of artwork also may have limited participants' understanding of the possibilities of this artform.

Navigation Issues. Navigating in the virtual environment also posed difficulties for participants. There was a lot of uncertainty for some participants when they were moving around the environment, if they were moving at all. Not knowing where the boundaries of the VR area were or where certain objects in the room were caused anxiety

about moving around. Not every participant knew that there were boundaries that would show them the perimeter of the VR area and not every participant necessarily knew what those boundaries meant. This again may be related to a lack of familiarity with the virtual environment.

Another interesting theme that emerged during participant interviews was a reluctance to move through artwork. Participant perceived their artwork like they would physical objects, something that they would be unable to step through or something that would be ruined if they were to step through it. Some participants were able to overcome this, but it took a mental adjustment. One potential benefit of Tilt Brush is that participants are not restricted by their artwork and can freely move through the virtual brushstrokes, but the tradeoff is that it is an unfamiliar experience that goes against the way objects are perceived and interacted with in real environments. This is a lot to overcome, especially for users that are unfamiliar or new to virtual reality.

The experience of moving through the artwork may have also been disorienting for participants, as moving through objects is an experience that can only be had in a virtual environment like this and may be confusing to experience. It is an experience that is difficult to process.

Users had difficulty with teleportation as a way of navigating. The most basic problem was that some participants did not understand what the teleportation feature meant when they used it. This can probably be traced back to a lack of clarity with the menu options. It may require an icon that better represents the concept of teleportation or a stronger description. It may also just be a matter of making the existing information stand out more so that the user can better understand it.

Some users found it difficult to perceive the distance they would teleport. The interface currently has an arc that leads to an icon that shows where the user can expect to land, but given the difficulty users have adjusting to the 3D environment, this may not be enough information for them to know where they will end up. Some of the environments are all one color, and it may be more difficult to perceive depth there. Even in the environments with depth, adjusting to the third dimension may still be difficult. Teleportation was also disorienting for some participants. It requires turning around to look back at where the user was, which can be difficult or cumbersome while wearing an HMD. It is also not a transportation method that is familiar from real life. Walking was enjoyable in Tilt Brush, likely because it matched expectations and perceptions of walking in a real environment. Teleportation is unlike traveling through a real environment, and instantly moving from one location to another is not an experience perceived in reality. This likely contributes to feeling disoriented or confused, especially if a participant is not expecting it or does not know where they will end up. This can disrupt the feeling of presence in the environment.

HMD Issues. Finally, there were issues that physical set-up of the HMD presented. The HMD itself is large and cumbersome to wear. It does not easily fit all types of hair, and it can be uncomfortable to wear with glasses. Some participants got tangled up in the cord attached to the HMD, or had to step over it while navigating the virtual environment. It is especially difficult when there is no way for the user to perceive the real environment around them. They only have the sense of touch to tell them where the cord is, and relying only on that can be difficult, especially when they are immersed in the virtual environment and may not be able to focus their attention on remembering

where the cord was. It can also be tiring to be standing up and moving around while wearing an HMD for a long period of time. This can contribute to usability issues as participants tire out while using the app. This also could pose accessibility issues for people with disabilities.

Research Question 3: Differences Based on Artistic Experience

The biggest differences between the group with formal artistic training and the group without formal training seemed to stem from different intentions in using Tilt Brush. The formal training group was more likely to want tools that could help them implement techniques for making the kind of art they wanted (i.e. geometric shapes, reference photo, grid, etc.) The groups without formal training did not necessarily have the knowledge to know how to implement the techniques the artists were using or had the desire to use the same kinds of tools.

The group without formal training's requests for more guidance and pre-made models showed a desire for help in making the artwork look good. These differences could be attributed to the difference in skill level between the groups as well as the differing goals they may have for artwork created with this app.

The differences in artistic knowledge may have contributed to these differing desires for using the application. There may also be different motivation in the group, where people that are serious artists may see Tilt Brush as a way to create new artwork, while people that do not consider themselves artists may just want to use Tilt Brush for fun and would be less concerned about the final product, and more concerned with the experience. Tilt Brush needs to strike a balance between meeting the needs of both groups.

Many of the usability issues found in Tilt Brush affected participants in both groups. For instance, turning off the straightedge was problematic for members of both groups. Both groups had issues being immersed in the virtual environment while still navigating in the real environment. Many issues with usability had more to do with lack experience or understanding of VR and navigating a virtual environment instead of lack of artistic training or understanding.

Research Question 4: Enjoyment of the Artistic Experience

It was overwhelming clear that participants enjoyed using Tilt Brush. In spite of the usability issues discovered in Tilt Brush, overall participants were able to use the application to enjoy creating art and express themselves. The factors that made Tilt Brush usable made it possible for this app to be an enjoyable experience. After analyzing the interview data several factors emerged that contributed to participants' experience of the app.

Immersion. Participants enjoyed the immersion within the app. The experience of being in a virtual world and getting to create artwork within it was enjoyable. The participants were literally able to immerse themselves in their own artwork. The experience of being in a virtual world can be fun because it allows for the possibilities outside of what is possible in a real environment. The idea that participants can also play a role in creating this environment adds another aspect to the immersion that makes it a good experience. Users can create the world they are immersing themselves in, and can create worlds for others to immerse themselves in.

The options for environments also contributed to this. Participants could immerse themselves in somewhere new and different, or they could use the environment as

inspiration to create artwork within. It gave them a new world to explore and add their art to.

Novelty. The novelty of Tilt Brush was also an aspect that participants seemed to enjoy. The experience of painting in 3D was unlike what participants had done before. Just the experience of doing something new and different can be thought-provoking. Getting to experiment with a new medium allowed for a different artistic experience.

The third dimension was definitely a contributing aspect to the novelty of this experience. Many participants were used to painting in two dimensions, so adding a third dimension introduced an entirely new perspective on their artwork. Even for participants who had worked in 3D mediums, Tilt Brush was still unique in being a virtual reality painting app. 3D digital painting could be a considered a unique medium itself.

The immersion was also a factor in the novelty of this experience. VR is not a commonplace technology, so getting to use it and become immersed in a virtual world was certainly outside the typical experiences one could expect participants to have with technology.

Tools. Participants did enjoy working with the different types of brushes in Tilt Brush and the effects they made. Some of the brushes offered effects to paint with, such as fire, snow, light, diamonds. These could be used within the painting to achieve a certain aesthetic or highlight a certain aspect of the piece. They were also interesting to look at and enjoyable for participants to use and experiment with.

Possibilities. Tilt Brush offered new possibilities for creative expression. The third dimension was novel and immersive and ability to paint anywhere within the 3D space was something that could only be possible in virtual environment with a third

dimension. The tools are also unique and could only exist in within 3D digital painting (there is not any way to teleport around a 2D painting, or use a "star" brush in traditional painting). The immersive environment allows the artist to immerse themselves in their creation and build a world around themselves. They can make this kind of artwork for others to experience. This opens up possibilities and artistic implications for creating something new.

Creative Outlet Tilt Brush succeeded in providing a creative outlet for participants. Several participants mentioned that they found using Tilt Brush to be relaxing. More participants also said that they found using Tilt Brush to be fun. Finally, Tilt Brush also allowed participants to express their creativity. The tools and interface provided a means to give users this kind of experience. They could immerse themselves in an environment that gave them inspiration to start painting, like the snowman, dress form, and space environments, or they could immerse themselves in an environment like a blank canvas when they could make the world look like anything they wanted, like the white, black, and pink lemonade environments. They had a variety of brushes to choose from to build their painting and add effects. They could spend time in a unique artistic environment, experimenting in a new medium.

Feasibility of HMDs. When asked if they would use this app again, several users expressed concerns about the feasibility of accessing an HMD. Not many people can afford a virtual reality headset and a computer powerful enough to run it. There is also an issue with finding enough space to set up a VR area. This limits access to this kind of technology. The lack of accessibility to VR limits the ability of potential users to have this kind of creative experience.

Limited Artistic Experience. While overall participants enjoyed using Tilt Brush, some participants did express that they felt limited by a lack of artistic skill. Some participants wanted more guidance on creating their painting, some participants even suggested having pre-made 3D models that they could add to their painting, such a tree or a hat for the snowman. Not feeling confident using a new artistic medium seems like it could be expected. The skills that participants brought into this application affected their ability to create with the application. Tilt Brush offered tools and environments that users of all skills levels could enjoy using and exploring, but participants with more artistic skills may have felt more confident in the artwork they were creating.

Conclusion

Tilt Brush is an application that is overall easy to use and provides users with the tools and interface necessary to provide a creative experience. Factors that contributed to the usability of the app were an interface that used on familiar conventions from 2D apps and provided guidance for unfamiliar 3D feature and navigation that was consistent with the way the participants moved in the real world. Factors that worked against the usability of the app were a lack of control over tools like the color picker and the brushes, missing that features that inhibited participants' abilities to create what they wanted, lack of clarity about how to use the menu, tools not being highlighted enough to show that they are in use, lack of familiarity with working in a 3D environment, uncertainty and nervousness moving around the virtual environment due to not being able to see the real environment, lack of clarity about what teleporting means, difficulty perceiving distance of teleporting, and physical issues with HMDs. The biggest difference between the group with formal training and the group without formal training, seemed to be that the group with formal training wanted more tools that would give them control over their artwork and make more techniques available to them. The group without formal training did not request such tools. A couple of participants from the group without formal training wanted to add pre-made models and shapes to their artwork, suggesting a desire for guidance and an easier time creating what they wanted in exchange for control. The factors that contributed to a creative experience for participants were: immersion,

novelty, the tools available through the app, the possibilities Tilt Brush presented for creating art, and the creative outlet Tilt Brush provided.

Limitations

This study had several limitations worth noting. The methods used for recruiting did not retrieve a sample that representative of all potential users for Tilt Brush. These results are not generalizable to the whole population of Tilt Brush users, but they do offer insights into usability issues that may exist for some users of Tilt Brush.

The study was also conducted only in Beginner Mode, since it was expected most participants would have never used Tilt Brush before. Advanced Mode contained more features (some of which participants wanted) and offers a slightly different experience that may have its own set of usability issues.

Due to the nature of the master's paper study, only one experimenter was able to conduct observations and code the interviews.

Future Directions for Research

A follow up study could be conducted specifically with users that are interested in creating VR art, either as a hobby or professionally. This may get a sample that is more reflective of typical users of Tilt Brush.

A follow up longitudinal study would also yield more information about the usability of Tilt Brush. For the most part, participants were using this app for the first time. It often takes practice for artists to be able to create the art they want using digital painting apps and learn how to use the program. Giving participants a chance to revisit Tilt Brush and have more time to learn the program would likely show usability issues that long time users have and the factors that contribute to those issues could also be

identified. It would also allow for a chance to study the usability of Advanced Mode in addition to beginner mode.

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Appendix

Study Script

Set-Up (Before the Participant Gets Here)

- Make sure you have materials for participant: consent form for correct student, giftcard, receipt slip

- Check desktop

- Check Vive and vive controllers

- Make sure TV is off

Introduction

Thank you for agreeing to participate in this study. Throughout this session I will be reading from a script to ensure that I give identical instructions to all participants. As a participant in this study, you will create a virtual painting using an app called Tilt Brush. I will observe you as you paint and take notes. Afterwards, I will interview you about your experience and record the audio for later transcription. Finally, I will ask you to fill out a short questionnaire.

Consent Form

Before we begin, I will go over important information about the study with you. Your participation in this study in is voluntary and you are free to stop at any time. The risks of participating are minimal. At any point during this session you are free to ask me questions, however, I might not be able to answer specific questions about how to use

Tilt Brush, due to the nature of this study. This study has no positive or negative implications for your academic status.

Here is information about the study you can review and keep. Take as much time to read over it as you need and let me know if you have any questions or when you are ready to begin.

How to use the Vive

To use Tilt Brush, you will need to use the HTC Vive. You use the Vive by putting on that headset and holding those controllers.

While you are using the Vive, I will be sitting there on that stool [point to stool] to take notes. I will be observing how you use Tilt Brush. I will remain quiet for the most part, unless I need to warn you about tripping over the cord or going too far outside the VR area. I am not observing to test your skill with Tilt Brush, so you can feel free to paint in whatever way feels most satisfying to you.

How to wear Vive:

After you get the headset on, I will explain more about the task of the study and hand you the Vive's controllers.

[Remember to cover]

- Glasses
- Head placement
- Knob on back

- Head strap

- Eye lenses

- Earphones

- Controllers

Let me know when you are ready to begin, or if you have any questions.

Study Portion

For this study, you will be using Tilt Brush to create a 3D painting.

[Hand controllers]

You can use these controllers to choose brushes, colors, and tools to create your three

dimensional painting.

I will now start Tilt Brush. Please wait for my instructions before doing anything in the

app. [Start Tilt Brush]

Please select "New Sketch" from the controller menu.

[If they need help] You can select it by pointing the other controller at the "New Sketch"

option on the menu and pulling the trigger.

[After they select]

Before you start the main task of creating a painting, I will give you five minutes to

familiarize yourself with Tilt Brush and its controls. I will ask that you keep the

application in beginner mode. Other than that, feel free to try whichever options of the

app you would like.

I will start the timer now.

[set timer]

[Stop participant after five minutes]

All right, are you ready to move on to the main task?

If you would like, you can clear the painting and start with a new environment by selecting "Clear Sketch" from the bottom menu of the controller.

I will give you twenty minutes to create a piece of artwork in Tilt Brush. You can create anything you want. Use any of the brushes, colors, or tools you would like. I will again ask that you keep the app in beginner mode.

I am going to set the timer again.[Set time]

Do you have any questions?

Tell me when you are ready and I will start the time.

[Take Notes]

[Timer goes off]

The twenty minutes have ended. You may hand the controllers back to me and remove the Vive.

[Put controllers away; remember to charge! Put Vive back on mount].

Interview/Post Study

We can now proceed to the interview portion of the study. Give me a second to set up the chairs, and feel free to take a seat.

[set up recorder]

This is the interview for participant [number]

To start off…

Interview questions to identify experience with painting:

- Do you have any formal training in art?

  - Could you describe it?

- Do you consider either digital painting or traditional painting a hobby?

Interview questions to get qualitative usability data:

- How was your experience learning how to use the Tilt Brush interface?

- How was the experience of walking around the environment? How was the experience of teleporting around the environment?

- Did you have any difficulties navigating around the painting?

  - Could you describe the difficulties you experienced?

- What did you find most difficult about using this interface to create your painting?

- How much did you enjoy painting in 3D? What did you enjoy the most about this experience?

- Would you use this app again? Why or why not?

- Was there anything you wanted to do while painting that you were unable to do?

- How did painting in 3D space compare to painting in 2D?

- Do you feel like you were able to express yourself while making this painting?

Follow-up Question:

- Could you tell me more about that?

Thank you for answering those questions. For the final part of this study, could you please fill out this questionnaire?

[Get laptop out, and hand it to participant]

Questionnaire

Start of Block: Block 1

Q7 Participant Number

_____

End of Block: Block 1

Start of Block: Default Question Block

Q1 For each statement, mark the number on the scale that best reflects how much you agree with each statement. 1 corresponds to Strongly Disagree and 5 corresponds to Strongly Agree.

	Strongly disagree 1 (1)	2 (2)	3 (3)	4 (4)	Strongly agree 5 (5)
I think that I would like to use Tilt Brush frequently. (1)	o	o	o	o	o
I found Tilt Brush unnecessarily complex. (2)	o	o	o	o	o

I thought Tilt Brush was easy to use. (3)	o	o	o	o	o
I think that I would need the support of a technical person to be able to use Tilt Brush. (4)	o	o	o	o	o
I found the various functions in Tilt Brush were well integrated. (5)	o	o	o	o	o
I thought there was too much inconsistency in Tilt Brush. (6)	o	o	o	o	o
I would imagine that most people would learn to use Tilt Brush very quickly. (7)	o	o	o	o	o
I found Tilt Brush very cumbersome to use. (8)	o	o	o	o	o
I felt very confident using Tilt Brush. (9)	o	o	o	o	o
I needed to learn a lot of things before I could get going with Tilt Brush. (10)	o	o	o	o	o

Q2 Are you of Hispanic, Latino, or of Spanish origin?

o Yes (1)

o No (2)

Q4 How would you describe yourself?

☐　　　American Indian or Alaskan Native (1)

☐　　　Asian (2)

☐　　　Black or African American (3)

☐   Native Hawaiian or Other Pacific Islander (4)

☐   White (5)

☐   Other (6) _____

Q3 What is your gender?

o Male (1)

o Female (2)

o Other (3) _____

End of Block: Default Question Block

Wrap-up/Giftcards

- Thank participant for coming in

- Give them their choice of gift card

- Make sure they sign the receipt