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# Evaluating Immersive Animation Authoring in an Industrial VR Training Context


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An important aspect of a Virtual Reality (VR) training application is animation, as animations can be used to present behavior and intent, and make the virtual space feel more alive and immersive. In existing VR applications and in the literature, several animation authoring solutions exist that enable users to create animations directly in VR. These solutions, however, typically aim to recreate the animation tools found in traditional 3D animation software, which are complex and known for their steep learning curves. For an industrial subject matter expert creating a virtual training space, an immersive animation tool should require little to no time to learn while still enabling users to solve common animation tasks such as simple 3D object animation. Few such tools exist, and little research has been done on animation authoring in an industrial VR context. In this paper, we present a mixed methods user study with seven participants including industrial subject matter experts. The participants were asked to complete three animation tasks using an immersive animation authoring tool developed for this study, followed by post-task questionnaires and a semi-structured expert interview. Thematic analysis of the interview and observation data, supported by the subjective measurements, revealed that industrial end users without animation experience found the animation tool both intuitive and easy to learn. The analysis also gave insights into the major challenges faced by non-animators when using the tool as well as possible solutions.



**CCS CONCEPTS • Human-centered computing → Usability testing**; **User studies**; **Virtual reality**; **• Computing methodologies → Animation**;

**Additional Keywords and Phrases:** VR authoring tools, 3D animations, industrial end users

**ACM Reference Format:**

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## 1 INTRODUCTION

Virtual Reality (VR) based training is gaining enormous tracking in a wide range of industries due to the benefits of knowledge retention, learning effectiveness and reduced costs [30]. Traditionally, these training scenarios are created by combining the knowledge of subject matter experts with the technical skills of VR developers and 3D artists and animators. In order to scale the creation of VR-based training, several research projects and commercial applications have attempted to remove the need for VR developers by enabling the subject matter expert to create the training scenarios in a low- or no-code environment or directly within VR [31, 32]. An important aspect of these applications is the ability to animate objects in the virtual space. Animations can convey intention, emotion, or other information [12], and they also make a virtual space feel more alive and can be used for storytelling purposes [20]. In an industrial context, such as VR training in the manufacturing industry, animations may also be used to communicate both the behavior of a piece of equipment and the intended behavior or interaction of the user. Previous studies on animation authoring in VR have demonstrated how VR tools can increase the sense of presence for artists [26], which in turn can increase their creativity and productivity [15]. The animation tools proposed in these studies, however, often resemble those found in traditional animation software, which are built for professional animators and provide great versatility at the cost of complexity and a steep learning curve [8, 20, 26]. For industrial use cases, the subject matter expert creating an animated VR training space often has little or no experience using traditional animation tools. While some studies have recognized the need for VR animation tools for industrial users [28, 29], the proposed solutions are highly specialized to specific animation tasks, and to the best of our knowledge no previous studies have evaluated the needs of industrial subject matter experts for general VR animation tools.

In this paper, we present a formative qualitative evaluation of a VR animation authoring tool for simple and intuitive performance animation of objects in VR for subject matter experts from the manufacturing industry. The purpose of the evaluation is to elicit the needs of these users and the requirements they have for a VR animation tool. The animation tool used as part of the user study contains an immersive animation path system that records the animated object’s translation and rotation in order to create a motion path presented in the 3D space. Individual keyframes can then be manipulated directly by the user, updating the motion path and providing continuous feedback. The animation path system is accompanied by a tablet-based menu providing access to the create, edit, and delete operations, as well as providing common animation settings. The formative evaluation presented was conducted as a mixed methods user study based on expert interviews and subjective questionnaires to evaluate the feasibility of immersive animation tools for industrial end users, as well as gain insights into limitations and possible solutions for these.

## 2 RELATED WORK

The creation of 3D animations within VR has been explored for decades. In 1995, Deering found that 3D animation in VR provided artists with a sense of freedom and direct control, even though the state of VR technology at the time relied on glasses with active shutter systems, stereoscopic 3D images, and controllers with poor tracking capabilities, severely limiting the quality of animations [10]. In more recent years, animation authoring in VR is still an active field of research, as the technology has matured to a point where the limiting factors are no longer the hardware but the software, and in particular, the interfaces provided to users [8, 26, 27]. In this work we draw on prior research and existing applications related to traditional animation tools in VR, VR authoring applications and VR animation tools for non-animators.

### 2.1 Traditional Animation Tools in VR

Several traditional animation software solutions, such as Blender, have started providing native VR support [13], enabling artist to preview scenes and animations in VR. Another company MARUI [21] has created plugins for traditional animation software, including Autodesk Maya, providing artist with tools they are familiar with while working in VR.

In the literature, there have also been some work focusing on bringing traditional animation tools into VR. Lamberti et al. [18] proposed VR Blender, an add-on for Blender that enables users to view a 3D scene and create and edit animations in VR from within Blender. VR Blender provides users with adaptations of the native tools enabling a range of animation tasks in VR including keyframing, performance animation and motion paths. In a continuation of this work by Cannavò et al. [7], the VR Blender add-on was extended with character animation capabilities including rigging, skinning, and posing. The extended VR Blender add-on also enables users to customize the interface provided in VR by mapping controller buttons to Blender functions or parameters. Vogel et al. [26] proposed AnimationVR, a plugin for Unity3D that brings the Unity animation timeline into VR for keyframing animation with support for animation layers with multiple objects. AnimationVR also supports performance animation and character animation with inverse kinematics (IK).

These solutions that extend existing animation tools have been shown to increase productivity of animation artists, enhancing their existing workflows [7, 18, 26]. However, since they extend and rely upon traditional animation software, they retain much of the same complexity and learning curve as these tools, hence making them unsuited for non-animators.

### 2.2 VR Authoring Applications

Standalone VR applications with animation authoring tools have also become more common in recent years. Tvori [25] is a VR application made for prototyping and storyboarding enabling artists to create animated movies. It provides a wide range of tools for keyframing, motion paths, character animation and more. Several of the tools provided have immersive 3D interfaces designed for VR, however, having such a rich feature set and being targeted towards artists, it has a complexity and learning curve similar to traditional tools.

Rec Room [17] is a world-building application with support for multiple platforms including VR. It enables users to create virtual rooms with various authoring tools including animation authoring. The animation system is based on gizmos and keyframing. Animated objects are added to animation gizmos that can be edited to create keyframe animations with a frame-by-frame approach. Rec Room is targeted at a younger audience, and the tools are relatively simple and easy to learn. The frame-by-frame approach, however, means that adding a new keyframe is a manual step repeated for each keyframe, making it less efficient.

### 2.3 VR Animation Tools for Non-Animators

In the literature several studies have focused on providing animation tools that are simple, easy to learn and immersive. Fender et al. [12] created a tool, Creature Teacher, enabling users with no animation background to create cyclic character animations with two-handed manipulation of the body parts, detecting and repeating cyclic movements. While the automatic detection of user intent is an interesting approach to improving learnability, the cyclic animation of characters is less relevant for industrial applications and more relevant for games.

Osawa et al. [23] proposed an immersive path editing tool for manipulation of control points along a motion path. They found that the direct manipulation of control points made the solution intuitive and easy to understand. However, they also found that it was less precise and proposed a gearbox interface for fine adjustment. For industrial use cases the very precise manipulation of control points, or keyframes, is less relevant. However, the direct and intuitive manipulation of a motion path in 3D space is an approach from which we draw inspiration.

Several studies have examined the use of hand gestures and sketching in VR to create 3D animations. Arora et al. [34] presented professional animators with a set of target animations in order to elicit a set of natural hand gestures they would use to recreate the animations. These gestures were then implemented in a prototype and evaluated with other animation artists. While this study was targeted professional animators and they focus on animating physical phenomena, gesture-based animation in VR is showing a lot of promise. However, for industrial end users animating 3D objects in a VR training context we believe that purely gesture-based animation authoring is too inaccurate. Future work, however, could examine extending other animation tools with the use of gestures to create an initial animation.

## 3 METHODS

This section describes the immersive animation tool developed for the user study presented in this paper. As the animation tool was developed and evaluated within the SynergyXR VR application, relevant parts of the application are described in Section 3.3. The VR application, and thereby also the animation tool, has been developed in the Unity3D game engine. The primary goals that guided the design of the animation tool were:

1. **Simple and easy to learn.** A minimal set of features and options included to keep interfaces simple and enable users without a technical background to use the tool with little to no training.
2. **Immersive and intuitive.** An animation tool that leverages the immersive nature of VR and relies on 3D interfaces rather than 2D interfaces.

### 3.1 Animation Path System

Previous work has shown that 3D interfaces can provide better usability for 3D animation tasks than 2D interfaces [19]. Therefore, one of the challenges we sought to solve in relation to the second design goal was to bring the traditional 2D animation timeline into the 3D space, thus utilizing the immersiveness of VR and 3D interaction techniques. Our proposed solution is to utilize motion paths as seen in traditional animation software and in literature [2, 18, 23, 26]. The animation path system enables users to record and edit animations in a very direct and visual way in the 3D space providing an immersive animation experience.

#### *3.1.1 Recording animations*

Users can record animations by grabbing and manipulating a selected object to generate keyframes at fixed distance intervals, the object manipulation techniques used are described in further detail in Section 3.3.1. This is an application of performance animation [33]. As keyframes are created a motion path will be drawn and updated, visualizing the current animation to the user as seen in Figure 1. Unlike traditional performance animation, where points in space are tracked and recorded over time directly [27], the animation tool presented here removes the time component from the performance phase. The keyframes generated record a position and a rotation, but not a time value. Instead, the time between keyframes is given by the function $t = t_{-1} + l/L * D$, where $t_{-1}$ is the time of the previous keyframe, $l$ is the length of the motion path segment between the previous keyframe and this one, $L$ is the total length of the motion path and $D$ is the total duration of the animation, with lengths defined as the Euclidean distances between keyframes. This results in a constant animation speed throughout the entire animation regardless of how long the user spent on a specific part of the animation. This design choice was made with regard to the first design goal as we found that the ability to adjust the time between keyframes is a more advanced feature and also less important in industrial use cases, and a constant speed would be the most intuitive default behavior. Furthermore, some common speed adjustments can be provided with the easing functions described in Section 3.2.1.

The keyframe distance interval used during the study was 35 cm, a value we arrived at during a pilot study described in Section 4. This value we found produced a path close to the motion made by the user, without generating more keyframes than necessary. The total duration of the animation is constantly updated with a timer that starts when the animated object is grabbed and pauses when the object is released, so that the duration of the animation is the time spent manipulating the object. During pilot studies, we found that this was an intuitive way to provide a default duration value that can then be edited through the tablet menu described in Section 3.2.


Figure 1: An overview of the VR animation authoring tool developed for the user study. An immersive animation path system with an accompanying tablet menu.

### *3.1.2 Editing animations*

To edit an animation, users can change the position and orientation of individual keyframes by releasing the animated object and targeting and selecting a keyframe. This will set the animated object to the position and orientation of the selected keyframe, and by manipulating the object users can then translate and rotate the keyframe as shown in Figure 2 (a). To continue the animation, users can select the last keyframe in the animation, and positional changes larger than the distance interval will then generate new keyframes.

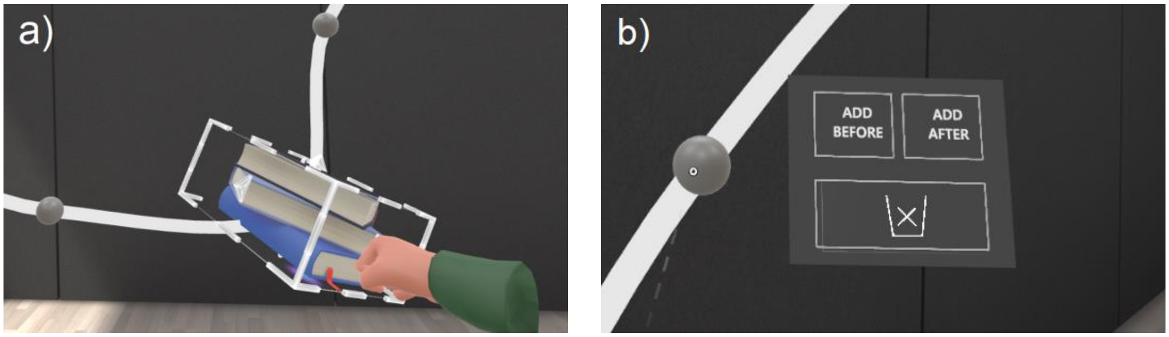


Figure 2: An overview of the keyframe manipulation options provided by the tool. (a) shows a keyframe being manipulated and the motion path reacting to the changes. (b) shows a keyframe context menu enabling users to delete and add keyframes.

Furthermore, targeting a keyframe will display the context menu shown in Figure 2 (b), enabling users to delete the keyframe or add a new keyframe before or after the targeted keyframe. As keyframes are otherwise automatically generated, this provides users with an easy way of achieving exact motion paths.

### 3.2 Animation Tablet Menu

While a design goal was to rely primarily on 3D interaction and interfaces, a simple animation menu was implemented to facilitate the animation process as well as provide some common animation settings. The menu provided users with a clear start and end point in the animation process, and provided access to basic create, read, update, delete (CRUD) operations.

The menu was designed to function as a tablet with some physicality inspired by the tablet menu from the VR game Lone Echo [1]. When spawned the tablet appears in front of the user within arm’s reach (50 cm). The tablet then stays in place unless grabbed and moved by the user with near- or far interaction, described in Section 3.3.1. All UI components in the menu can be interacted with from a distance with raycasting or with direct touch interaction.

The main page of the animation menu, shown in Figure 3 (a), enables users to select the active animation object and the active animation if any. It also provides access to CRUD operations and has a progress bar for controlling the active animation. Creating or editing an animation will switch the menu to the edit page.

Figure 3 (b) shows the edit page of the menu, which provides the user with common animation settings such as the duration, and whether the animation should be looping or play automatically. It also provides smoothing and easing options, described further in Section 3.2.1, and a progress bar visualizing the keyframes in the animation at their place in the timeline. This provides users with a second method of selecting the active keyframe during editing, as the progress bar will snap to the keyframe closest to the new progress value when changed. This in turn will update the position and orientation of the animated object, to that of the selected keyframe, same as if the keyframe had been selected in the 3D space as described in Section 3.1.2.

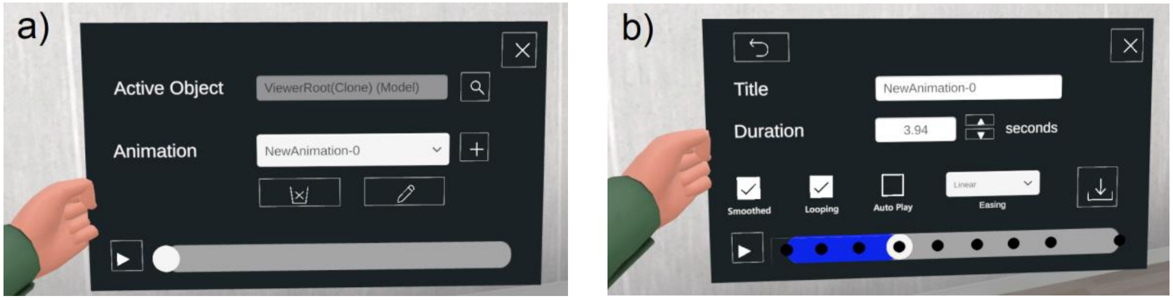


Figure 3: The animation tablet menu. (a) shows the main page, enabling users to select the animated object and create, edit, delete, play, and pause animations. (b) shows the edit page containing common animation settings, a progress bar with the keyframes made visible and save or discard buttons.

#### *3.2.1 Smoothing and easing functions*

The smoothing option determines whether the motion path should contain smooth, curved segments between keyframes, or whether the segments should be straight lines. The smoothing is implemented using Unity3D animation curves and the smooth tangents feature. This will make the in- and out tangents around keyframes line up, creating a uniform slope.

The easing dropdown menu provides users with five common easing functions that can be applied to the animation, changing the rate at which the animation evaluates the animated parameters over time. These include ease-in, ease-out, ease-in-out, bounce, and linear.

### 3.3 VR Application

The animation tool was developed as a feature within the SynergyXR VR application, available on the Meta Quest 1 and 2 devices. The application is targeted towards industrial end users and enables companies to create virtual spaces to which various virtual content can be added. In the user study presented in this paper, participants were not subjected to creating and editing virtual spaces and these features will not be described further. However, participants did rely on the object manipulation and locomotion methods used in the application and these are described in the following sections.

#### *3.3.1 Object Manipulation*

The application relies on the Mixed Reality Toolkit (MRTK) [22] for all methods of interaction including object manipulation and interaction with 2D interfaces. MRTK enables several interaction paradigms including simple direct manipulation and raycast manipulation for near- and far 6 degree of freedom (DOF) manipulation [3]. It also enables manipulation based on a bounding box with translation, rotation and scale handles [16]. Using the handles on the bounding box allows for translation or rotation with 1 DOF and uniform scaling. In this VR application, direct and raycast manipulation is performed with the grip button on the Meta Quest controller, while bounding box handles are activated with the trigger button.

#### *3.3.2 Locomotion*

The application relies on the teleport locomotion method regularly found in modern VR applications [4], activated by pushing the thumbstick on the Meta Quest controller forward. Besides teleport, fixed rotation snapping of the viewpoint [11] is available for users by pushing the thumbstick to the left or right enabling users to easily reorient themselves in the virtual environment.

### 3.4 Known Limitations

In the current version of the animation tool, all animations are made using the animation path system, which is based on motion paths. This means that while it is possible to create an animation with only a change in rotation, it will not create a visible path and will thus be difficult for users to edit. For this reason, the animation tasks included in the user study all contain translation. The animation tool in its current state also does not enable animation of scale as we found this less relevant for industrial use cases where the correct and realistic scale of an object is a priority. However, we do not foresee any challenges in enabling this in future versions of the tool. Participants in the user study were made aware of these limitations during the introduction to the animation tool.

## 4 USER STUDY

This section describes the user study conducted as part of this work. Prior to the user study described here, a small initial pilot study was made with three participants recruited from the SynergyXR company. This pilot study was performed in order to test and refine the animation tasks as well as the data collection methods. This initial study also allowed us to test and adjust some of the settings and assumptions made in the design of the animation tool based on the performance of the participants. These settings included the distance between the automatically generated keyframes described in Section 3.1.

For the main user study, to gain insights into the needs of industrial users and to assess the usability of the animation tool we conducted an inductive mixed methods study based on domain expert interviews. During a session, a participant would have time to freely explore using the tool, after which they would be asked to complete three animation tasks. After completing the tasks participants would be asked to fill out a post-task questionnaire followed by a semi-structured interview. The sessions were designed to last 60-80 minutes. Seven participants from three different domains were recruited. None of the experts had participated in the previous pilot study. All participants had experience using VR while the animation experience varied between the groups. The following research questions guided the design of this study:

**RQ1** What are the major challenges for industrial subject matter experts when using an immersive path editing tool in VR?

**RQ2** Does an immersive path editing tool help non-animators feel the connection between object and animation?

### 4.1 Participants

We recruited seven participants from three groups of users based on quota sampling. The main group consisted of three industrial subject matter experts from a manufacturing company, all with prior experience with VR training applications and with the SynergyXR platform. In addition, acting as control groups in the study, a group of VR developers and a group of animation artists were included. Two VR developers and one animation artist were recruited from the company and the last animation artist was recruited externally.

All participants had prior experience using VR. Both VR developers, one animation artist and one industrial end user use VR on a daily basis. Two industrial participants use VR on a weekly basis and the remaining animation artist had used VR on a few previous projects. Furthermore, both VR developers had some experience creating animations, while the industrial participants had little to no previous experience creating animations. Table 1 provides an overview of the participants and their self-reported experience levels.

Table 1: An overview of the participants in the user study and their self-reported level of experience in VR and in creating animations in general. The experience levels are rated on a 1-5 scale.

| ID | Group | VR Experience | Animation Experience |
|---|---|---|---|
| P1 | VR developer | 5 / 5 | 3 / 5 |
| P2 | VR developer | 5 / 5 | 3 / 5 |
| P3 | Animation artist | 5 / 5 | 4 / 5 |
| P4 | Animation artist | 2 / 5 | 5 / 5 |
| P5 | Industrial expert | 5 / 5 | 1 / 5 |
| P6 | Industrial expert | 3 / 5 | 1 / 5 |
| P7 | Industrial expert | 4 / 5 | 1 / 5 |

### 4.2 Experiment Setup

The animation tool was developed inside the SynergyXR VR application for the Meta Quest 2 standalone head-mounted display (HMD) using the Unity game engine. Oculus Touch controllers were used for input and since all participants were familiar with VR and with this particular HMD, little introduction to the equipment was needed. During each session the HMD would be set to stream to a monitor so that the performance of the participants in VR could be observed.

In the VR application, four virtual spaces had been prepared in advance, one for the free exploration phase and one for each of the three animation tasks. The four virtual spaces all placed the participant within the same neutral room of 10x7 meters. Virtual objects had been placed in advance for the participants to animate. For the animation tasks, the space contained two copies of the objects, one for the participant and one that was playing the target animation that the participant had to recreate. The animation tasks and their setup is described in more detail in Section 4.3.3.

### 4.3 Procedure

Initially, participants were introduced to the procedure of the study, what they would be asked to do and what data would be collected and how. Then, they were asked to fill out a consent form as well as a demographic questionnaire, assessing their previous experience with VR and with creating 3D animations. After the general introduction, the session would continue with the following four phases.

#### *4.3.1 Introduction to the animation tool*

In the first phase of the session, participants were introduced to the animation tool via demonstration by the researcher. This demonstration was scripted, and each feature was presented in the same order and fashion for each participant. Participants were also introduced to the known limitations of the animation tool described in Section 3.4.

#### 4.3.2 Exploration

During this phase, participants would put on the HMD, set to the prepared virtual space for the exploration phase. Participants were then given 20 minutes to freely animate the provided virtual object and explore the animation tool. During this phase participants were asked to think-aloud about their experiences.

#### 4.3.3 Animation Tasks.

After the exploration phase, the participants were presented with three animation tasks. Each task had its own virtual space that was prepared in advance. In each of these virtual spaces, two setups were presented to the participant. One setup was already animated and showed the participant an animation they had to recreate to the best of their ability. The other identical setup was for the participant to animate. An overview of the tasks and their setup is provided in Figure 4.

The animation tasks were designed to test different types of motion paths including movement in a straight line, an organic jumping motion and a circular path. The different motion types were chosen in order to increase the exposure to the animation tool and gain insights into its limitations and to see how the participants would approach these different types of challenges. To avoid any domain-knowledge bias, the objects chosen for the animation tasks were not from the industrial participants' domain, but rather generically relatable objects. The objects were all a similar size and shape in order to remove possible effects of manipulation of different objects, as previous studies have shown interactions between object size and the manipulation method used [14].

During this phase participants were again asked to think-aloud about their experience completing the tasks. Participants were given 10 minutes to finish a task, after which they would be asked to move on to the next task. The order of animation tasks was randomized to remove possible order effects.

#### 4.3.4 Interview

After completing the animation tasks, participants were asked to remove the HMD and complete the post-task questionnaire. Following this, the semi-structured interview would be conducted. The questionnaire and semi-structured interview are described in more detail in Section 4.4.

### 4.4 Data Collection

The data collected during the user study consisted of subjective measurements collected with a post-task questionnaire, as well as the qualitative data from observations and semi-structured interviews.

The post-task questionnaire contained two parts. The first part included a standard System Usability Scale (SUS) [6] in order to assess the general usability of the animation tool. The second part measured user satisfaction using the animation tool. This part was based on the Questionnaire for User Interface Satisfaction (QUIS) [9], using seven questions proposed in previous work with animation interfaces [18, 24], as well as two new questions regarding the usefulness and the aesthetics of the proposed animation tool.

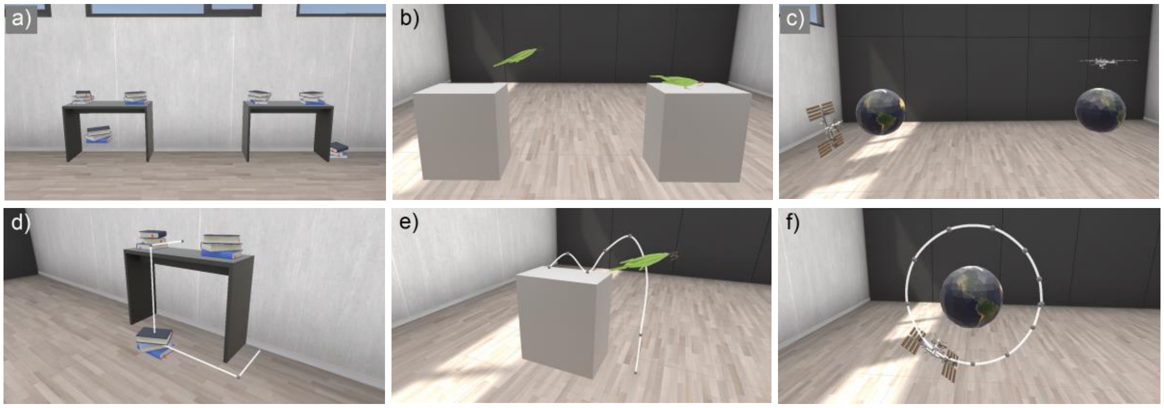


Figure 4: The animation tasks in the study included (a) moving a stack of books from the floor unto a table, (b) moving a frog from a pedestal down to the floor in a jumping motion, and (c) orbiting a space station around a globe. (a), (b) and (c) shows the tasks as they were presented to participants, while (d), (e) and (f) show the motion path of the target animation.

Observations from the think-aloud process as well as the performance of the participants followed on the monitor were noted during both the free exploration and the animation tasks.

The semi-structured interviews conducted at the end of each session were audio recorded and later transcribed verbatim. The interviews consisted of seven open-ended questions that could be reordered or skipped depending on the flow of the discussion. For the VR developer and animation artist groups, interviews were conducted one-to-one. However, for the industrial participants, a group interview was conducted due to logistical constraints for the participants. The industrial participants still had individual exploration and animation task phases as well post-task questionnaires, only the interview was in a group.

## 5 RESULTS

This Section presents the results of the subjective measurements from the post-task questionnaire, described in Section 4.4, as well as the analysis of the expert interviews. During the user study, all participants completed all animation tasks. The study took on average 81.6 minutes ($SD$ = 12.14) including the entire procedure described in Section 4.3.

### 5.1 Subjective Measurements

In the first part of the post-task questionnaire, participants were asked to evaluate the general usability of the animation tool based on the SUS questionnaire. Normalizing the scores on the 0-100 scale, the animation tool was rated as above average ($M$ = 78.93, $SD$ = 12.06), with 68 being considered an average score.

The second part of the questionnaire asked participants to rate their satisfaction with the animation tool on several aspects based on the QUIS questionnaire. The results of this part of the questionnaire are presented in Figure 5.

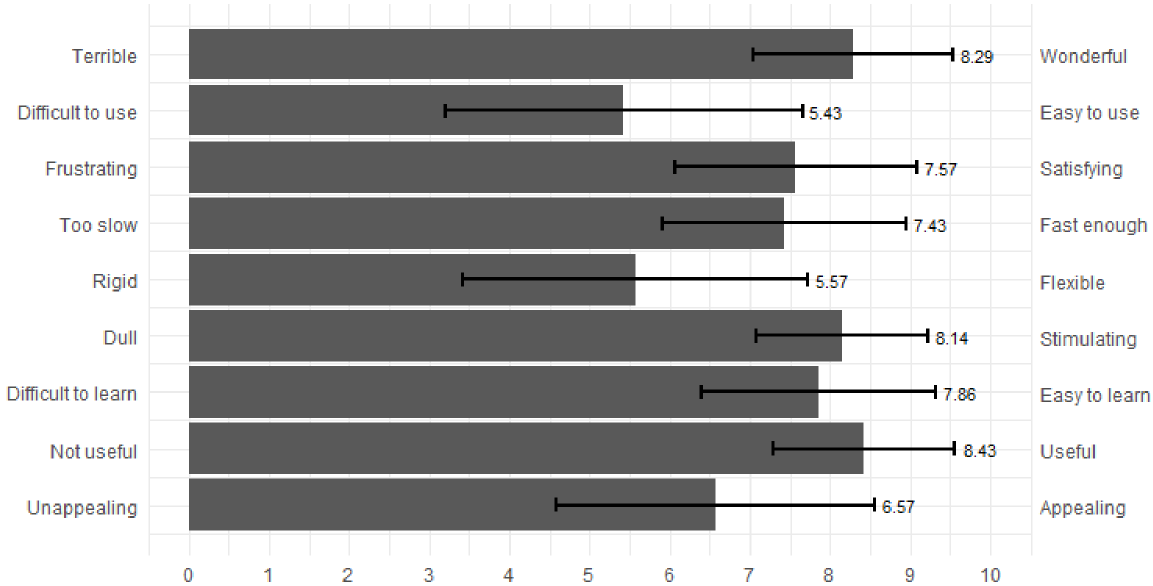


Figure 5: Subjective measurements of user satisfaction from the QUIS questionnaire, showing the mean (bar height) and standard deviation (error bar) values.

### 5.2 Thematic Analysis

The expert interviews were transcribed verbatim, and the transcriptions were analyzed along with observation notes using thematic analysis [5]. Coding was performed following an inductive approach and guided by the research questions presented in Section 4. Initially one coder processed approximately 70% of the interview and observation data, while a secondary coder processed the remaining 30%. The first coder then performed a second iteration of coding, merging and removing overlapping codes, and organized codes into emerging themes and subthemes. Themes, subthemes, and salient extracts were reviewed and refined iteratively guided by the research questions. The thematic analysis resulted in three themes, each containing two subthemes, described in the following sections. One interview was conducted in English while the rest were conducted in Danish. Therefore, most of the salient extracts presented have been translated.

#### *5.2.1 Immersive tools in VR are intuitive and easy to learn*

Participants generally found the immersive animation path system intuitive and easy to learn, and the salient extracts fall into two subthemes: 1) Instant feedback, 2) and Feeling connected.

**Instant feedback.** Five out of the seven participants reported that the direct interaction with the model, along with the instant feedback from the animation path system, made it easy and fast to learn.

> P2: "I'd say, it's easy to learn, because it's such a direct interaction with the animation. You just grab it, move it, and you can see the path change immediately."

Three participants also noted that it made it easy and fast to get a rough animation.

> P1: "It just made sense, right away. The constant feedback is great, and you get 80 percent of the way really fast, and the rest is just tweaking."

One of the animation artists, being very experienced using 2D timelines from traditional animation software, was almost exclusively selecting the 3D keyframes in order to review the current animation.

> P4: "I was surprised, actually, that I didn't use the UI more. But I think it's just, being able to very visually see it makes it easy."

**Feeling connected.** All participants reported feeling a direct connection to the object and the animation and several participants mentioned feeling absolute control over the animation.

> P7: "I like that it's just, so immersive. You're working directly with the model, making changes in the 3D space."

The participants often forgot the animation tablet while creating their animations and they enjoyed the direct relation between object and the individual keyframes as they selected a keyframe and the object moved to the corresponding position and orientation.

> P2: "I preferred using the path directly, there you have the direct relation to the keyframe."

### *5.2.2 Object manipulation is an important feature in immersive authoring*

The biggest frustrations for the participants were when the object manipulation method did not perform as expected or intended. As an animation tool, most participants felt that the features provided were sufficient in the context of industrial use cases. Most of the features requested by participants were targeted at the manipulation of the virtual object and the extracts fall into the subthemes: 1) Meeting expectations, 2) and Manipulation options.

**Meeting expectations.** One participant found the manipulation handles on the bounding boxes difficult to use in part due to expectations from other tools.

> P4: "I think the handles on the object were difficult to find, and then when I found them, they were difficult to grab. They should be different colors, and bigger."

Several of the participants also experienced that the bounding box of the object would overlap with several keyframes in some cases, making them unable to select those keyframes.

> P5: "It was annoying, when the space station would always overlap and block the next keyframe. Like an invisible barrier."

**Manipulation options.** Most of the features and changes requested by the participants were targeted at the manipulation of the object and keyframes.

> P4: "I mentioned animation layers. I don't think they're that important really, but being able to select and manipulate multiple keyframes, that's going to make things so much easier, and faster."

A few participants wanted more control over the keyframing process while manipulating the object.

> P5: "I'd like to be able to decide when it creates a keyframe. So, when I've grabbed it, every time I press another button maybe, it creates a keyframe, to have more control. And I'd rather add more keyframes later, than have to delete a bunch of them."

Another feature requested by three participants was the ability to change the time of individual keyframes.

> P3: "I think that it's missing just being able to move keyframes in the timeline. For example, I'm animating, and then I find out that the timing in the end is way too slow. But the rest of my animation is great. I would like to just be able to move those last couple of frames."

#### *5.2.3 Precision should be provided by the system*

As participants commented on the quality and precision of the animations they created, participants were more interested in sensible defaults and proposals by the system rather than precise manipulation techniques. Salient extracts fall into the subthemes: 1) Motion path templates, 2) and Relative manipulation.

**Motion path templates.** Several participants commented on the difficulty of creating precise curved motion paths.

> P3: "Linear paths were easy, you could just use the translation handles. Curved paths, including multiple keyframes and getting the angles right and smooth, it was hard getting it really precise."

Participants in the group interview proposed giving the user the option to select a motion path template to start from.

> P6: "If you wanted a circular motion, you could just go and pick from a prefix, and then make it smaller or larger. Then you could have a straight line, an arc, an ellipse. That could be fast."

**Relative manipulation.** Four participants mentioned being able to visualize, move and rotate a keyframe relative to the neighboring keyframes.

> P2: "The space station was hard because I had to edit and rotate all the keyframes on the curve individually. And I couldn't really see the rotation relative to the other frames, so it became a bit more uneven that I had imagined."

The ability for keyframes to snap to the position and/or orientation of a previous keyframe, in order to easily make small adjustments between a sequence of keyframes, was also mentioned.

> P1: "If you could snap keyframes relative to each other, then you could align things easier, that would make sense. Because I'm probably not going to make huge changes between keyframes, and then I could edit the keyframe relative to the previous."

## 6 DISCUSSION AND FUTURE WORK

In this paper, we presented a mixed methods user study with domain experts including industrial subject matter experts. The participants were subjected to different animation tasks using a VR animation authoring tool developed for this study and the results indicate that the proposed animation tool is both intuitive and easy to learn. After the short introduction to the study and the tool, it was observed that all participants were able to immediately create animations without assistance. Participants commented that the direct interaction with the animation made immediate sense and that the instant feedback from changes to the animation made the tool fast to use. This is supported by our thematic analysis as well as the results from the QUIS questionnaire with high scores in ease of learning and speed, as well as an above average usability score in the SUS questionnaire. Extracts from the theme presented in Section 5.2.1 show that the design decisions regarding the animation path system and direct manipulation of keyframes are promising interfaces for animation authoring for non-animators.

Results from the QUIS questionnaire also show an average score for ease of use with a high standard deviation. From the qualitative analysis we can see that this is due to the bounding box manipulation method used with the animation tool. Several participants reported frustrations with overlapping bounding boxes as well as manipulation handles that were difficult to select. We believe the high deviation is due to the fact that three participants were very experienced using the SynergyXR VR application from which the manipulation method was borrowed. Three other participants had used the VR application before but were less experienced, and the last participant had never seen or used the VR application before. Although all participants were able to complete the animation tasks with animations resembling the target closely, these results show the importance of the manipulation methods and techniques used in conjunction with animation authoring tools in VR. This is an effect that to the best of our knowledge has not been investigated in previous studies and in future work it would be interesting to compare different manipulation methods for their effectiveness and usability while completing animation tasks in VR.

Several new features were proposed by the participants during the interviews, most of them related to the manipulation of keyframes. In particular, several participants mentioned being able to select and edit multiple keyframes or being able to manipulate keyframes relative to the ones just before or after, having the system snap the position or orientation of a keyframe to the values of another keyframe, when the values get close. We believe that this feature in combination with onion skinning, an animation technique that shows several frames of an animation simultaneously, would make it easier and faster to adjust a sequence of keyframes in small increments between each keyframe.

As seen in the salient extracts presented in Section 5.2.2, one participant from the animation artist group commented on the fact that the time between keyframes could not be adjusted. As described in Section 3.1 this was a design decision made for the sake of simplicity over flexibility. This prioritization is also reflected in the results from the QUIS questionnaire, with an average score on the rigid-flexible scale. Since this limitation was only commented on by an experienced animation artist, we find that this design choice is appropriate for an animation tool targeted towards industrial subject matter experts. It could, however, be interesting to investigate how the adjustment of time between keyframes could be afforded in an immersive 3D motion path editor.

## 7 CONCLUSION

We have presented a formative evaluation of an immersive animation authoring tool for industrial VR users to explore the needs and requirements for such a tool. The mixed methods user study included three participants from an industrial manufacturing company as the main group as well as two animation artists and two VR developers as control groups. The participants were subjected to three animation tasks followed by an expert interview, and we have contributed a thematic analysis of interview and observation data as well as subjective measurements. Our qualitative analysis, supported by results from SUS and user satisfaction questionnaires, show that participants found the animation tool intuitive and easy to learn, due to the direct manipulation of keyframes and the instant feedback provided by the animation path system. Through our interviews we have also elicited several potential improvements and features that may guide the development of animation authoring tools for industrial VR use cases. We hope that the methods and insights presented in this paper can help inform and inspire future work on VR authoring solutions for industrial use beyond the scope of animations.


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