Cartoonimator: A Paper-based Tangible Kit for Keyframe Animation

Krithik Ranjan
krithik.ranjan@colorado.edu
ATLAS Institute, University of Colorado Boulder
Boulder, Colorado, USA

Peter Gyory
peter.gyory@colorado.edu
ATLAS Institute, University of Colorado Boulder
Boulder, Colorado, USA

Seneca Howell
seneca.howell@colorado.edu
ATLAS Institute, University of Colorado Boulder
Boulder, Colorado, USA

Therese Stewart
gstewart42@student.cccs.edu
ATLAS Institute, University of Colorado Boulder
Boulder, Colorado, USA

Michael L. Rivera
mrivera@colorado.edu
ATLAS Institute, University of Colorado Boulder
Boulder, Colorado, USA

Ellen Yi-Luen Do
ellen.do@colorado.edu
ATLAS Institute, University of Colorado Boulder
Boulder, Colorado, USA

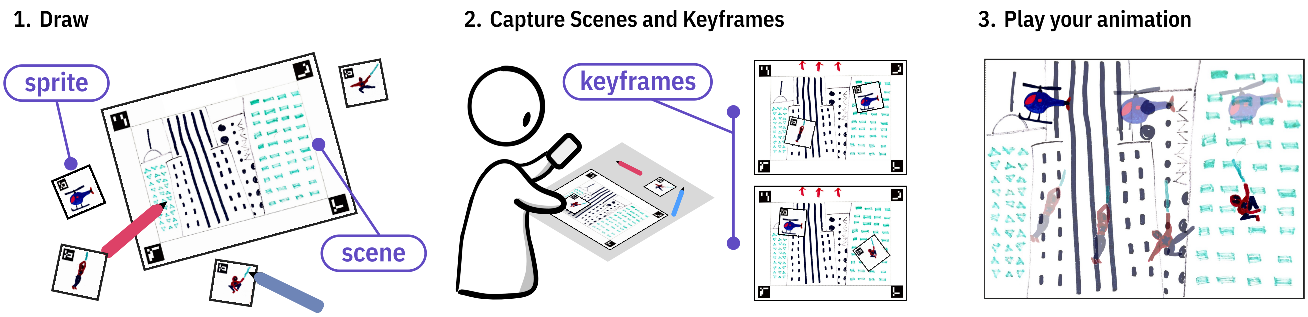

Figure 1: Creating an animation with Cartoonimator in three steps.

Abstract

Animation unlocks exciting creative opportunities to express one's ideas and stories. However, creating animations with existing software or tangible interfaces is difficult and time-consuming. In this paper, we present Cartoonimator, a paper-based tangible kit for keyframe animation that enables novice animators to quickly create animations from illustrations on paper. The kit—comprising paper templates to draw scenes and characters on, and a mobile web app to capture keyframes and compile the animation—offers an engaging tangible interface for both children and adults to create versatile animations. We conducted system evaluations with adults and workshops with children to study their interaction with the tool and the kind of animations it enabled. Our findings reveal that Cartoonimator is an intuitive and expressive tool that lowers the barrier to animation and helps users learn about animation concepts.

CCS Concepts

• **Human-centered computing → Interactive systems and tools**; Mobile phones; • **Computing methodologies → Animation**; *Computer vision.*

Keywords

tangible interaction, paper-based interfaces, animation, keyframing

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1 Introduction

Sketching is a powerful creative avenue for one to express their ideas and stories. Animation, or a timed sequence of pictures, offers this creative expression an additional temporal dimension. Animation enables people to communicate stories and concepts that are dynamic in nature in an engaging manner. In learning, animations help reduce cognitive load and understanding of dynamic concepts [5]. However, creating animations is challenging. The traditional, stop-motion methods of animation like flipbooks and claymation

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can be very tedious—to produce even a short animation, the animator needs to assemble dozens of frames in sequence. On the other hand, commercial computer animation tools like Adobe Animate and Blender offer precise and flexible controls for complex animations but are difficult for novices and children to learn and use [3]. Children and non-professional animators may only want to create quick and simple animations, like a lecturer animating a concept illustration, or a child animating a story they wrote—tasks that are not as approachable with these sophisticated tools [38].

Over the past decades, researchers have explored tangible means to engage young learners and novices with animation. Video Puppetry [3] enables children to animate their drawings on a digital scene by directly moving the cut-out drawings in front of a camera, while Animated Drawings [37] uses Machine Learning to animate hand-drawn characters automatically. In 3D space, 3D Puppetry [13] and more recently, AniCraft [21] also use puppetry-style or *motion capture* animation to create animations by direct manipulation of physical objects. Such tangible interfaces for animation revert the art of animation to a more hands-on, craft-based experience and offer an intuitive, playful, and multi-sensory learning opportunity [22]. However, these interfaces are all designed for short, partial animations of characters and further require extensive setup such as stationary webcams [3, 13, 21] or head-mounted displays [21], which makes them difficult to use in practical and educational settings.

We present Cartoonimator, a paper-based tangible interface for keyframe animation that facilitates quick and easy creation of complete animated stories from hand-drawn or printed illustrations on paper. Cartoonimator utilizes the *keyframing* animation technique commonly used in commercial animation software (e.g. Adobe Animate[1]) to enable creators to build long, complex animation through digital interpolation—the software automatically fills in the gaps between two animation *keyframes*, so the user only needs to define a limited number of frames. The Cartoonimator kit consists of (1) paper templates to draw scenes and characters for the animation, and (2) a smartphone application to capture frames and develop the animation. Cartoonimator utilizes computer vision (CV) algorithms running on the smartphone to detect and process the illustrations on the paper templates and produce digital animation. Cartoonimator's workflow, illustrated in Figure 1, involves three steps: (1) create the scene background and characters, (2) capture keyframes using the smartphone application, and (3) play and view the animation. Cartoonimator enables working with 10 common animation operations—interpolate, translate, rotate, scale, appear, disappear, define cels, morph, repeat motion and set timing (Fig. 4)—which cover more than 80% of the common animation use cases [10].

We designed Cartoonimator to be used by creators of all ages in a variety of settings, whether they are young children with wild stories to animate or adults who want to animate as a hobby or for work. In this paper, we describe the design and use of the kit, our process of evaluating it with adult users (ages 19-34), and observations from a series of play-testing workshops with children (ages 6-10) in a real educational setting of a summer camp. We sought to investigate whether Cartoonimator helps lower the barrier to animation for children and novice animators, and how they approach the activity of animation through this kit. Overall, we found that all the participants saw Cartoonimator as an engaging and easy-to-use tool to explore their ideas and stories through animation, and it helped users learn about and apply animation concepts. The workshops also highlighted further improvements that can be made to the system before deploying it in the wild. To that end, we present the following contributions:

(1) The open-source Cartoonimator animation kit—consisting of the smartphone application, the paper templates, and usage instructions. The kit can be accessed at the project website[2].
(2) Quantitative results and findings from user evaluations of Cartoonimator centered on usage of the tool, animation learning, and interest.
(3) Qualitative observations from three workshop case studies with children examining their interaction with Cartoonimator, focusing on their engagement and creativity with the tool.

We first introduced Cartoonimator as a work-in-progress paper showcasing the initial prototype and learnings from its pilot deployment [29]. This paper presents the latest version of the Cartoonimator kit and reports on its evaluation with adults and children.

2 Background

2.1 Computer Animation Tools

Animation has long existed as an art form of moving pictures. Like static drawings, animation has served as a creative outlet for adults and children alike, who may begin animating from a young age using flipbooks and claymation [4]. These are both types of stop motion animation, one of the earliest animation methods that involves playing static frames made with drawings or clay figures in rapid succession to conjure an illusion of motion [42]. With the help of modern computers and software, the medium of animation has become more approachable and less time-consuming than stop-motion.

Past literature describes four modern computer animation techniques: keyframe animation, procedural animation, motion capture animation, and picture-driven animation [2, 26]. In *keyframe* animations, animators define the "key" points in an animation, and a software program interpolates between them to create a complete animation. *Procedural* animation involves scripts, rules, and simulations to generate animation, like kinematic animations that use the physical properties of joints and linkages to simulate a moving body. The *motion capture* technique tracks the motion and position of an actor or object to animate a digital character. Lastly, *Picture-driven* or *sketch-based* animation [39], where one can define the movement by sketching the motion trajectory, is used especially in tools for novice animators.

Despite the advancements in technology and the variety of animation tools available today, researchers have found that these tools remain difficult to use for amateurs, who often only want to create animations in an informal context [3, 38, 39]. This has propelled the development of a range of tools targeting novice animators and simpler animations. These include K-Sketch [10] and Sketch-n-Stretch [38], all *sketch-based* animation interfaces. A

[1]https://www.adobe.com/products/animate.html

[2]https://cartoonimator.glitch.me/

few of these tools are centered toward children (e.g. Scratch and ScratchJr [11, 30] which use *procedural* animation). To make animation more engaging and approachable, a few researchers have developed paper-based tangible interfaces for users to animate their drawings on paper. These include Video Puppetry [3] which uses a *motion capture* technique, and Draw2Code [16], which enables animations in Augmented Reality using the *procedural* method. However, these tools have a low ceiling for the animation they offer, either with the number of characters (Draw2Code) or the type of movements (Video Puppetry). Cartoonimator expands the genre of paper-based animation by enabling the creation of longer and more versatile animations than prior work through the use of the *keyframing* technique.

2.2 Tangible Interfaces for Creative Learning

Tangible user interfaces (TUIs) provide "tangible representations to digital information and controls, allowing users to grasp data with their hand and effect functionality by physical manipulations of these representations" [36]. TUIs computationally augment physical objects to provide a digital coupling that can act as both input and output for the users. TUIs can offer unique approaches to integrating digital technologies that can be more engaging and intuitive than traditional Graphical User Interface (GUI) based technologies. Given their physical nature, these interfaces have been found to support one's spatial cognition, reduce cognitive load, and enable more creative immersion [19, 36]. Tangible interfaces have been employed in various learning environments like classrooms, museums, homes, etc., enabling students to learn by creating with computers in "the world" [31]. These include computationally-enhanced construction kits for robotics (e.g. Cubelets [34]), tangible programming interfaces (e.g. Tern [14], Cubetto [40]), game-based learning (e.g. Bots & (Main)frames [25]), storytelling (e.g. StoryBlocks [20]).

Many tangible learning interfaces center around the practices of making and tinkering—a playful and experimental form of engagement driven by learners' motivation and interest [32]. The tangible and craft-based approach has been used to engage learners to build computational artifacts with physical materials in an open-ended and collaborative manner. These interfaces offer more flexibility in divergent thinking and encourage open-ended exploration and expressive activities [1, 22]. The learner-driven approach in tinkering experiences supports learners in creating their own identities by developing confidence, persistence, authorship, and new ways of thinking [41].

Examples of tangible interfaces for tinkering include MakeyMakey[3], Chibitronics [28], and MCVT [27] that enable learners to create interactive electric circuits with materials like paper, aluminum foil, copper tape, and fruits. Researchers have also utilized computer vision (CV) to recognize passive, paper-based tangibles without the additional cost of setting up embedded electronics. For example, PrototypAR [17] helps students learn about complex systems by cutting and assembling paper cut-outs. In the domain of animation, previously mentioned Video Puppetry [3] and Draw2Code [16] enable children to animate their hand-drawn characters, while Kart-ON [35] offers a paper programming cards to create and animate digital shapes. Cartoonimator expands upon this open-ended TUI paradigm for animation by enabling the creation of complete animated stories with several characters and scenes. Like Kart-ON and Draw2Code, Cartoonimator utilizes paper and mobile devices to suit a range of educational settings. Further, as revealed in our studies and workshops, the paper-based form factor of the kit supports craft-like tinkering and experimentation with the materials to achieve unique animations, which was not supported by previous toolkits.

[3]https://makeymakey.com/

3 Cartoonimator

We have developed Cartoonimator as a paper-based, tangible kit to make it easy and engaging for anyone to learn and create animations. The kit uses smartphones and paper templates printed using a common printer to make it more attainable for diverse settings without expensive equipment or software. Throughout the design process, we considered the design guidelines put forward by Resnick and Silverman [33] for construction kits for children—we sought to make Cartoonimator very easy and quick to get started with (low floor) while enabling the creation of complicated animations with many scenes and characters (high ceiling).

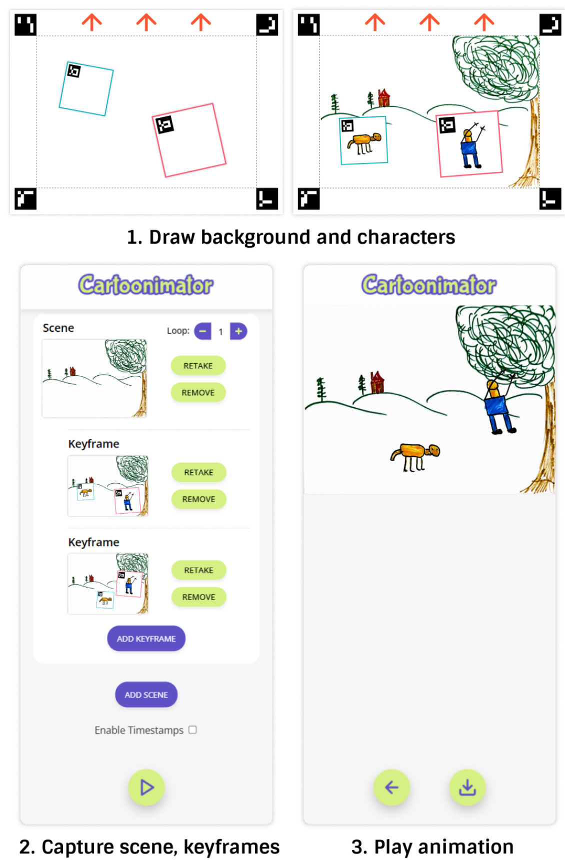

Figure 2: Components of the Cartoonimator kit: (1) scene sheets and object cards, (2, 3) Cartoonimator web app. This is an analog to Figure 1 illustrating the three steps of drawing, capturing, and playing using the app interface.

3.1 System Overview

The Cartoonimator system comprises (1) paper printed with fiducial markers, and (2) a smartphone application (Fig. 2). The paper component of the kit consists of (1a) scene sheets on which users can draw the background for their animation, and (1b) object card templates to draw characters (*sprites*). One can also choose to add digital illustrations to the template background and characters. The sheets contain fiducial markers on each corner, which enable a child to capture the scene from any angle—the app uses the markers to flatten and crop to the actual scene using a CV technique called *homography*[4]. The object cards are smaller square paper sheets with a reference marker at the top left corner and a colored border. Using CV *thresholding* algorithms, Cartoonimator subtracts the background and the marker from these object cards to place them seamlessly on top of the scene. A user can add multiple sprites to the animation using multiple object cards with different markers and border colors. Object cards of the same border denote the same character, and can be used to define different *cels* or forms of the same character (e.g. a flying bird character can have one card with wings down and one with wings up to show flying). The background sheet and object cards can be sized to suit the users' preferences—we have extensively tested common print sizes of 8.5"x11" and 11"x17" for the background and 2"-5" for the object cards.

We bundled the Cartoonimator application into a mobile website that enables the users to capture the scenes and the keyframes, assign timestamps, and view the complete animation (Fig. 2). The application can be used on most mobile browsers (tested on Google Chrome, Microsoft Edge, and Apple Safari), and does not require any additional installation. We built the app using the OpenCV [6] and ArUco [12] libraries in Javascript to perform the ArUco fiducial marker recognition, and rendering of the animation. Figure 3 shows how the application processes the scene and keyframes captured to create the complete animation.

3.2 Workflow

To create an animation with Cartoonimator, the user first draws or prints a background image for their scene on one of the scene sheets and one or more character sprites on the object cards. Once all the assets are ready, they can begin creating the animation with the app, as illustrated in Figure 2. The user begins their animation with their first scene by capturing only the scene sheet. Then they place the object cards on top of the scene to specify the position and orientation of each sprite and capture a keyframe. The sprites can be moved, rotated, or modified to capture the next keyframes to progress the animation. The system linearly interpolates each sprite's position, rotation, and size over successive keyframes to create the intermediate frames in the animation. The animator can also add multiple scenes to the animation, each with a different background. Finally, they can play the completed video, download it, and share it with others.

The default interval between each keyframe in the animation is 0.5s, which we decided on after preliminary testing—half a second interval resulted in snappy transitions with enough control over the speed of movements. The "Enable Timestamps" toggle also allows for manipulating the time of each keyframe. A scene can be repeated a number of times by manipulating the "Loop" counter for that scene. The rest of the scenes will play in the order in which they were captured in the app, either before or after the repeating scene. Multiple scenes can be looped in the same animation.

3.3 Animation with Cartoonimator

Cartoonimator imitates the keyframing workflow of traditional desktop *keyframing* computer animation software (e.g. Adobe Animate[5]), in which animators create digital characters or sprites and position them on top of the animation background (*scene*) to specify different keyframes of the animation. Similarly, Cartoonimator enables novices to create complete animations using *keyframing*, while learning about animation concepts such as *sprite*, *scene*, and *keyframe*.

Based on their analysis of 72 usage scenarios, Davis et al. [10] define 18 common animation operations that tools may support. We designed Cartoonimator to be a versatile, paper-based animation kit, and support many of these animation operations while remaining intuitive for children. The final tool enables animators to perform the following 10 operations: interpolate, translate, rotate, scale, set timing, appear, disappear, define cels, morph, and repeat motion. These many operations can support more than 80% animation scenarios, as per the analysis conducted by Davis et al. [10]. The table in Fig. 4 describes how these operations can be executed using Cartoonimator.

4 System Evaluation with Adults

In order to study how users interact with the Cartoonimator system, we conducted a system evaluation where adult participants got to try out the tool. The study comprised two tasks, one involving the recreation of two sample animations with Cartoonimator, and the other being an open-ended interaction with the system where the participants could create their own animations. Considering our design goals of low floors (easy for novices) and high ceilings (not limiting for experienced users), we recruited adults with varying exposure to animation to see how they approached the tool. Our goal with this study was to assess the user experience of working with Cartoonimator, and understand how the tangible interface can help lower the barrier of entry to animation. We also looked at how interacting with Cartoonimator can help participants learn animation and develop an interest in the art. Specifically, we sought to answer the following research questions in this evaluation.

- RQ1: How does the Cartoonimator tangible kit lower the barrier to animation?
- RQ2: Does Cartoonimator help users learn about and use animation concepts and operations?
- RQ3: How does interacting with Cartoonimator affect users' interest and perception of animation?

4.1 Participants

We conducted this study with 9 participants between the ages 19 - 34 (μ = 25.2, σ = 5.5). They were recruited from the authors'

[4]Homography is a image transformation or mapping between two planar projections of an image. It is used in Cartoonimator to flatten the captured scene to a 2D picture.

[5]https://www.adobe.com/products/animate.html

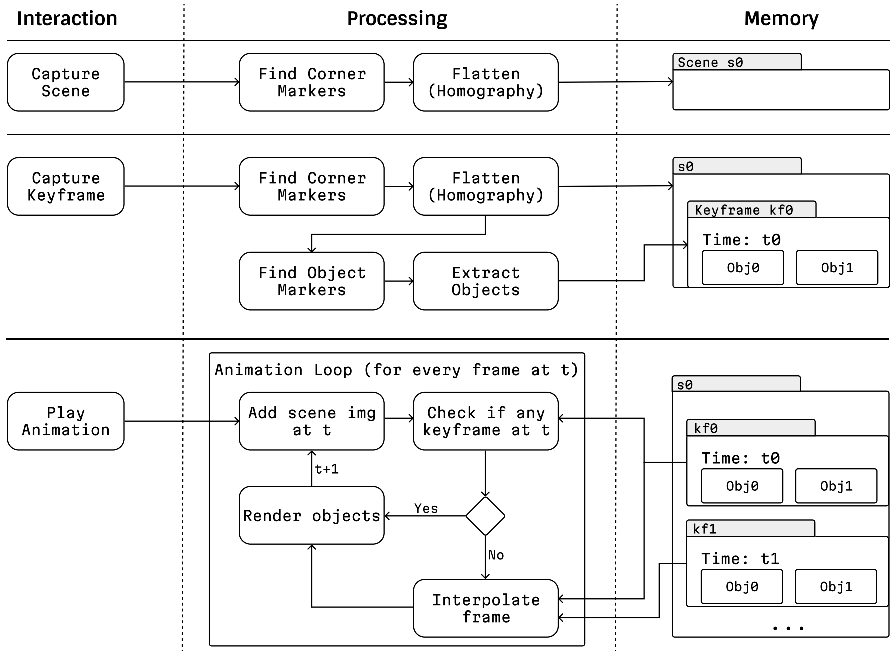

Figure 3: Image processing pipeline of Cartoonimator for the interactions of capturing scenes, capturing keyframes, and playing the animation.

personal contacts and comprised of undergraduate and graduate students, and administrative staff connected to the authors' institute. They generally had none to some amount of animation experience—when asked to rate their prior experience on a scale of 1-5, four participants responded 1, two responded 2, and three responded 3 ($\mu = 1.9$, $\sigma = 0.9$). The ones with some experience had used tools like Flash, Unity, Processing/p5.js, Procreate and some stop-motion apps. Table 1 summarizes the distribution of the participants and their experiences.

4.2 Procedure

Each participant took part in one individual session lasting about 1 hour and 30 minutes. In the study, we first introduced Cartoonimator to the participants and demonstrated its use with the help of an example animation. We described each of the features of the system and provided a handout resembling Figure 4 as a reference.

Once the participants were familiar with the system, we asked them to complete the Recreate Task, where they had to use Cartoonimator to animate two sample animations shown to them. This task was meant to enable the participants to try out all the basic features and animation operations possible with the system before moving on to creating their own animations. It also helped us assess the ease of getting started with Cartoonimator after a short introduction. The two sample animations used in this task are shown in Figure 5 (please refer to the supplementary video to see the animation in action). The first animation was about a bee flying around and then into a flower and reappearing thereafter, while another flower is waving in the breeze. It involved the usage of multiple characters, and the animation operations of translation, rotation, and appear/disappear. The second animation had a butterfly fluttering around the grass and completing two loops on the scene. This involved usage of multiple object cards to define cels for the fluttering animation, and using the loop feature to repeat the motion. For both these animations, we provided the participants with prepared assets that they could use to create the animations. This task lasted up to 15 minutes, depending on how long it took the participants to complete both animations.

The Open-Ended task gave the participants an opportunity to creatively interact with Cartoonimator and build animations for any idea or story they were interested in. We broadly structured this part of the study into three phases—(1) storyboarding, (2) asset creation, and (3) animation with Cartoonimator—to assist the participants in their brainstorming and creating process. While the participants could create an animation about anything, we also provided a prompt—"An Underwater Adventure"—that they could choose to follow. For this part, we provided the participants with some blank paper to sketch and storyboard on, blank Cartoonimator kit assets in different sizes (8.5"x11" and 11"x17" for scene sheets, and 3"x3" and 4"x4" for object cards) that they could draw on, and pens and color markers to draw with. Since the focus of the study was animation and not drawing, we also gave the participants an option to use images from the internet to create assets for their animation digitally—we provided a Google slides template with the scene sheets and object cards that they could add pictures to and print. The participants were asked to plan and create an animation in 30 minutes, but we allowed for flexibility of up to 45 minutes to not disrupt their creative intentions.

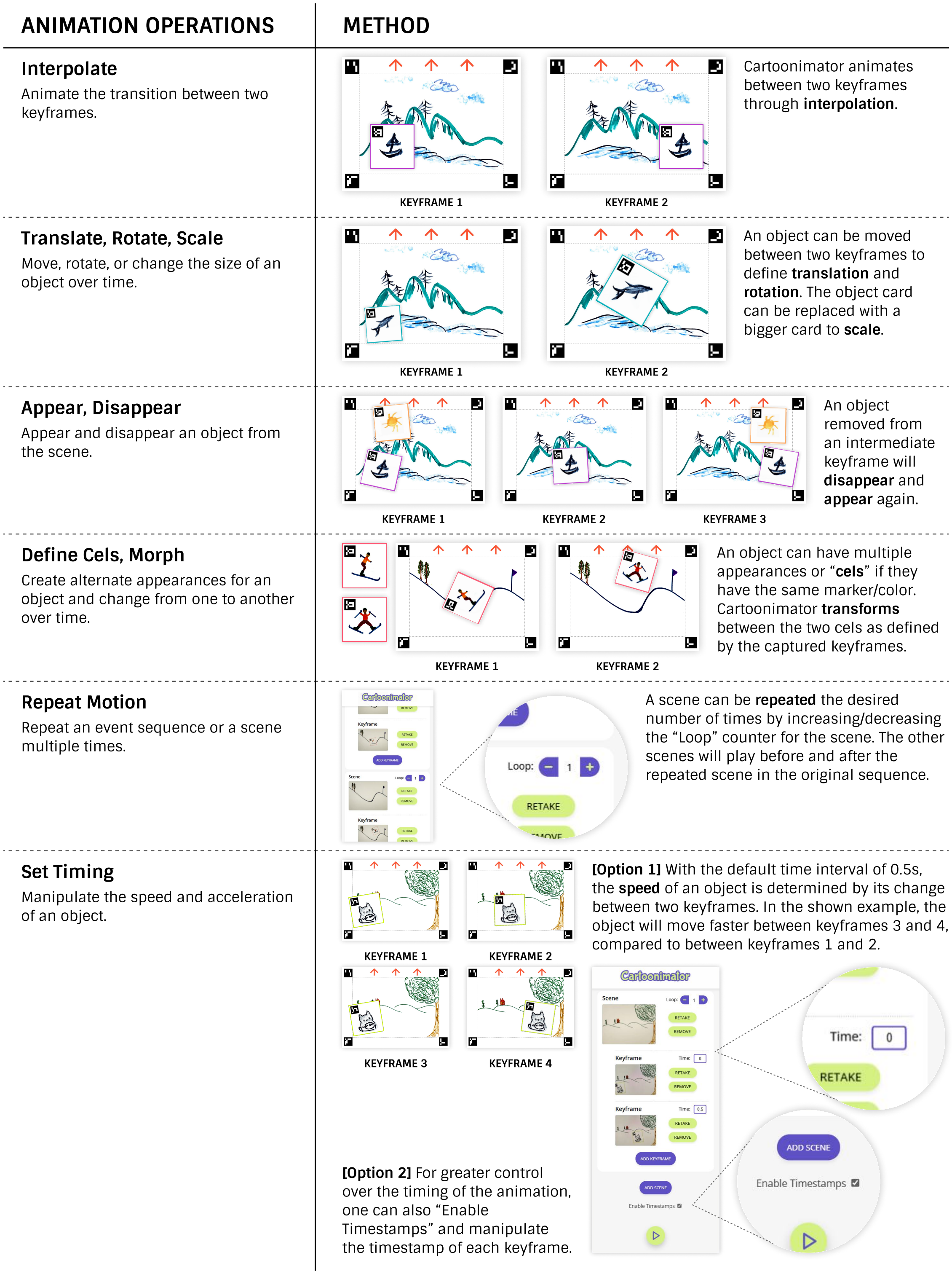

Figure 4: Range of animation operations possible through Cartoonimator.

Table 1: Participants' ages and prior animation experience.

ID	Age	Gender	Occupation	Animation Exp.	Tools Used
P1	29	Female	PhD Student	2	Flash, p5.js
P2	34	Male	PhD Student	3	Unity, Stop motion apps
P3	19	Male	Undergraduate Student	1	None
P4	28	Female	Graduate Student	2	After Effects, Processing, Flash
P5	28	Female	Academic Advisor	1	None
P6	20	Male	Student	1	None
P7	19	Female	Student	1	None
P8	21	Other	Student	3	Procreate, Premiere Pro, Piskel, Photoshop
P9	29	Female	PhD Student	3	Keynote, Photoshop, Stop motion apps

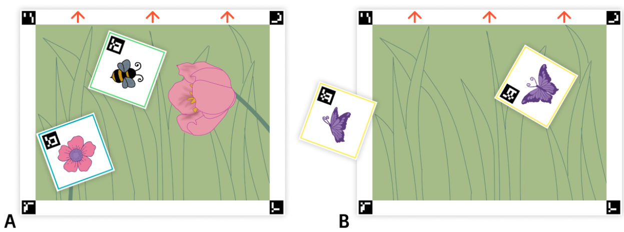

Figure 5: Assets provided for the animations in the Recreate task.

4.3 Data Collection and Analysis

To investigate our research questions, we collected a range of quantitative and qualitative data about participants' interaction with the tool and the animations they created. This included pre- and post-questionnaire responses, full session videos, screen recordings from the phones used, and a semi-structured interview at the end. The data collected through each of these methods is described below.

4.3.1 Questionnaires. At the start of the study, each participant filled out a pre-questionnaire before they were introduced to Cartoonimator or any animation concepts. This pre-questionnaire asked the participants about previous exposure to animation and their experience with any animation tool or software. The survey also asked them to rate their interest in animation (1-5) and to describe their apprehensions about animation, if any. Lastly, the survey asked them to rate their familiarity with common animation concepts described later in this section.

After completing both the Recreate and Open-ended task with Cartoonimator, the participants were given a post-questionnaire that asked them to rate their familiarity with the same animation concepts as in the pre-survey. This survey also consisted of statements about their experience with Cartoonimator that they were to rate on a Likert Scale (1 = strongly disagree, 5 = strongly agree). These statements were centered on the dimensions of *enjoyment*, *usability*, *interest*, *expressivity and creativity*, and *engagement and immersion*. We adapted these statements from prior studies on creativity support [8], situational interest [7, 24], and user engagement [43].

In both the pre- and post-questionnaire, the participants were asked to identify five key animation concepts—*keyframing*, *tweening*, *sprites*, *loops*, and *timing*. One of the authors of this paper—who has 3 years of informal animation and animation teaching experience—identified these as the core concepts used in Cartoonimator and keyframe animation in general. These are also recognized as important animation concepts in Adobe's educational articles[6]. Our goal with these questions was to see whether interacting with Cartoonimator can help users recognize these key concepts. We focused on *concept recognition* to assess learning about animation and animation concepts, but not in-depth learning of animation, which would take longer term and regular interaction with the tool. To compare the differences between the pre- and post-test of familiarity with concepts, we used the Paired T-test method [15].

4.3.2 Video and Screen Recording. Throughout the study session, we set up an audio/video recording of the participant's interaction with Cartoonimator. Accompanied by notes taken by the research team, the recording helped us record verbal and non-verbal observations about the user experience. This included any utterances or quotations as the participants were completing the tasks, or unique ways of interacting with the system, as well as any bugs observed during the interaction. The phones that the participants used to complete both tasks with Cartoonimator also had screen recording in place, which helped us record how they completed the tasks and any interaction nuances that we could not observe externally. We also used the screen recordings to analyze the open-ended animations they created and log the animation operations they used.

We used these two types of recordings to analyze how the participants completed the tasks and the animations they created. In the Recreate Task, we measured the time taken by the participants to complete each animation as well as the accuracy of the animation they created compared to the samples shown. We quantified the open-ended animations created by the participants to measure their understanding of different features of Cartoonimator and common animation operations. This included logging the complexity of the animation based on the number of scenes, keyframes, sprites, and sprite cels used. Further, we checked for usage of the animation operations supported by Cartoonimator (Figure 4)—translate, rotate, scale, appear/disappear, define cels/morph, set timing, repeat motion.

[6]https://www.adobe.com/creativecloud/animation/discover.html

4.3.3 *Semi-structured Interview.*

At the end of each study, we conducted an open-ended interview with the participants to broadly inquire about their experience with Cartoonimator and the study. These involved artifact-based questions about what they created in the open-ended task, their experience animating with Cartoonimator, and opinions about different features. We also asked them to reflect on their perception of and interest in animation before and after interacting with Cartoonimator and the role of animation in their life. Specifically, we asked the questions listed in Table 2.

Table 2: Qualitative questions the participants were asked after interacting with Cartoonimator.

	Questions
1.	Tell me about what you created.
2.	Describe the process of how you created your animations.
3.	How was the experience of animating with Cartoonimator?
4.	What features of Cartoonimator stood out to you and how did they affect your process of animation and the story you were trying to convey?
5.	What are some challenges you faced while interacting with the tool?
6.	What did the paper-based interface enable/disable you to do while creating your animations?
7.	What were your perceptions about animation before coming to this study?
8.	If you were previously interested in animation, what was the appeal or the challenges?
9.	How has your perception of animation changed after interacting with Cartoonimator?
10.	Do you think you learned animation in this workshop?
11.	What role do you see animation play in your daily life?

The freeform responses in the interview and other comments by the participants were first transcribed from the video recording. Then, the research team thematically analyzed the responses and picked relevant quotations along the three research questions, as well as other emerging themes.

4.4 Findings

This section presents the results and observations from the pre- and post-questionnaires, video and screen recordings, and the semi-structured interview to address our research questions. The quantitative results from the questionnaires are summarized in Fig. 7 and Table 3. The broader implications of these findings are discussed along with those from the workshops with children in Section 6.

4.4.1 *RQ1: Lowering the barrier to animation with a Tangible Interface.*

Participants found it easy to interact with Cartoonimator and be creative. They felt that they were able to "understand the features of the tool" (μ = 4.4, σ = 0.6) and were able to "create what they wanted with it" (μ = 4.6, σ = 0.5). In response to the statement of "I could not do what I wanted with the tool", the participants mostly disagreed (μ = 2, σ = 0.9). In the interview, all the participants commented on how easy it was to interact with Cartoonimator. For instance, P5 commented how it was *"easy enough to be used and understood by someone who doesn't have a background in animation or computer science"* (P5). The participants remarked that the keyframing technique makes it *"very simple to create those little animations"* (P6).

The participants in the study agreed that Cartoonimator allowed them to be expressive (μ = 4.6, σ = 0.5) and also helped them "develop novel ideas" (μ = 4.5, σ = 0.72). In the open-ended task, we saw them produce all kinds of stories with Cartoonimator (Figure 6). These included single character animations, like a bouncing cat (P2), skateboarder on a rink (P6), or hiker climbing a mountain (P5). Some animated a story with many characters, like a mermaid coming out of a shell and swimming around fish (P1), or a mommy duck leading her ducklings into the water (P4), or a sailor going on a boat to catch a big fish (P3). P9 created an animated data visualization of the number of fish in the Pacific ocean, showing the bar chart gradually decrease as the years progress. The variety of animations created by the participants showcases how Cartoonimator supported their creativity in pursuing different ideas and animations of their choice.

Throughout the tasks, the participants faced some challenges in interacting with Cartoonimator. These included bugs introduced due to computer vision (CV) or quirks in the user interface, and have been described in further detail in a future section (5.3.2). However, these "glitches" are not disruptive, P2 noted, as *"you can start over really quickly, which reduces frustration, reduces the mental load"* (P2). Reflecting on the tasks, the participants also identified how it takes planning to create an animation with Cartoonimator, whether it is *"figuring out what will stay stationary in the animation and what will change"* (P9), or making sure that all the markers are visible and not overlapping with each other. Therefore, the process of *"storyboarding was helpful"* (P1), as it engaged the animators to think about what they wanted to do with the scene and plan out the assets and their interactions.

Cartoonimator's tangible interface offered unique animation opportunities. In the interviews, 3/9 participants explicitly remarked how the paper-based interface of Cartoonimator enabled them to be creative and expressive—they like *"drawing by hand and designing the little characters"* (P4). It encouraged them to *"make the story"* how they want to (P6), compared to other beginner tools, where *"sometimes you have those pre-built things, and sometimes, maybe, that's all you have"* (P6). The paper also let them be *"spontaneous"* with their creations (P9), such as adding/changing characters until the end. P7 and P9 also appreciated the flexibility of combining hand-drawn and digital assets while working with Cartoonimator—*"I think it's really cool that you can get the pictures from online, because I don't draw and I'm not good at it, so that was really nice that I didn't have to worry about that"* (P7).

While animating with Cartoonimator, we noticed that the participants primarily worked in the physical space, either storyboarding or creating their assets and planning out the animation. The structure of scene sheets and object cards guided their creativity, instead of interfering with their creative process, and the smartphone app was only to *"take photos frame by frame, after drawing all the characters"* (P4). P1 *"drew out the sprites first and then put them on here [scene] and just kind of played around with them to see how they would show up"*. The tangible interface lends itself to making the tool more accessible and expressive for users. As noted by P1, *"I really didn't feel like I was having a software experience. I felt like I was crafting, and then, the software was like a secondary thing that I was thinking about."*

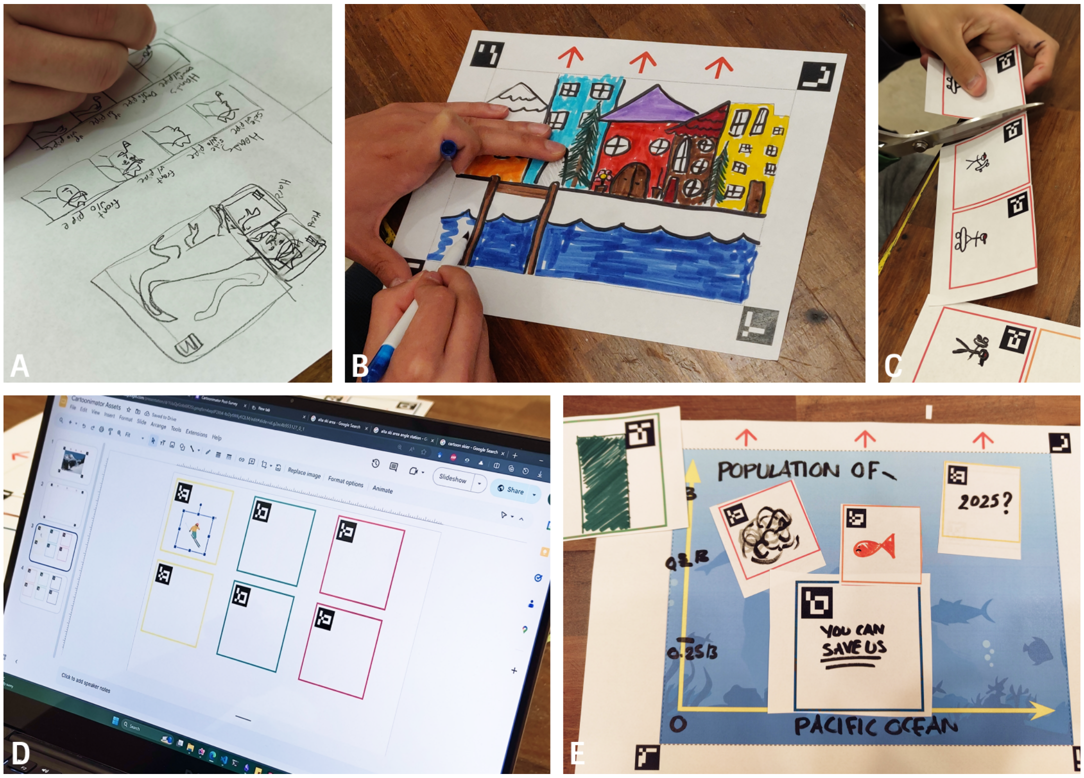

Figure 6: Pictures from the system evaluation sessions. (A) P8 storyboarding their idea. (B) P3 creating the background of their animation. (C) P6 cutting object cards for the sprites. (D) P7 creating their assets digitally. (E) P9's animation of a bar chart of the population of fish in the Pacific Ocean.

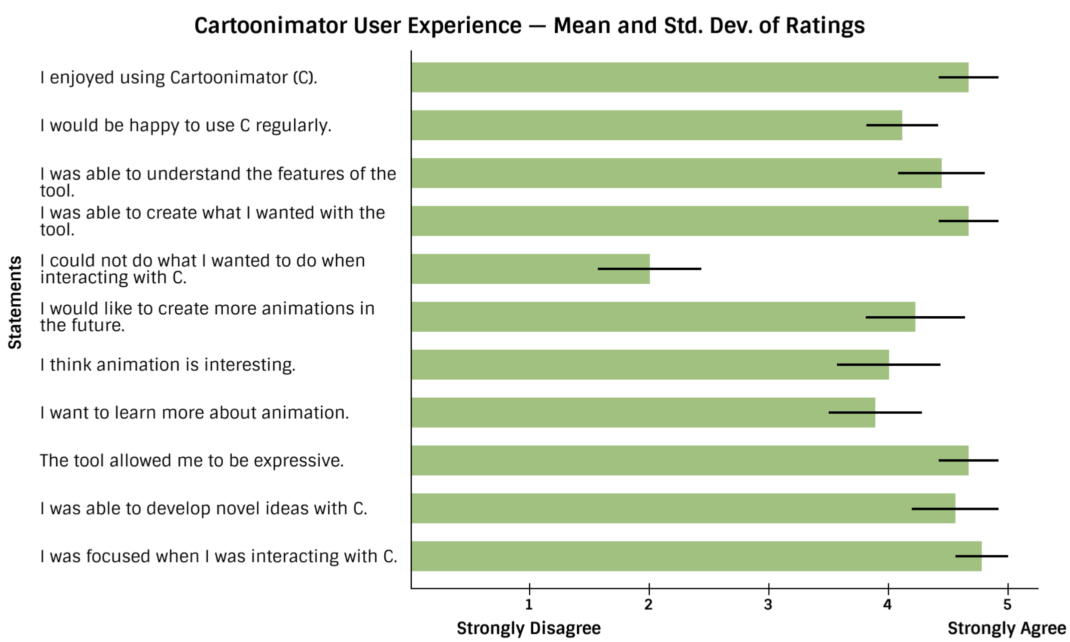

Figure 7: Statements and results from the post-Questionnaire given to the participants after interacting with Cartoonimator. The Participants were asked to rate each statement on a Likert Scale from 1 (strongly disagree) to 5 (strongly agree).

Table 3: Participants' Familiarity with Animation Concepts.

Concept	Pre (μ)	Pre (σ)	Post (μ)	Post (σ)	p Value
Keyframing	2.78	1.78	3.78	0.97	0.028
Tweening	2.11	1.54	3.44	1.24	0.028
Sprites	2.89	1.62	4	1.12	0.021
Loops	3.22	1.92	4.44	1.01	0.074
Timing	2.33	1.58	4.11	1.27	0.012

4.4.2 RQ2: Learning Animation and Animation Concepts. **Participants were able to quickly learn animating with Cartoonimator.** After a short introduction to the tool at the beginning of the study, all the participants were able to independently interact with it and complete the Recreate Task of animating a sample animation. The first bee and flower animation involving two sprites and the operations of translate, rotate, appear/disappear, was completed in 4 mins and 54.2 seconds on average (μ = 294.2s, σ = 84.7). Participants completed the butterfly animation with multiple sprite cels and the loop feature in 5 mins and 42.6 seconds on average (μ = 342.6s, σ = 160.9). The animations they recreated resembled the given samples to a reasonable degree—they utilized the relevant animation operations and performed the exact transitions with some allowance for variation in the position and rotation of the sprites. Three participants (P2, P4, P7), however, didn't do the loop in the second animation until it was pointed out, which they attributed to forgetting it or misunderstanding the animation.

Participants' recognition of animation concepts improved after interacting with Cartoonimator. As a means to evaluate whether interacting with Cartoonimator helps users learn about animation, we measured the participants' recognition of common animation concepts that they were exposed to through the tool on a scale of 1-5 through the pre- and post-questionnaires. Overall, there was an improvement in the familiarity of all the five concepts, as summarized in Table 3 with statistical significance ($p < 0.05$ on the Paired T-Test) for four out of the five concepts—*keyframing*. *tweening*, *sprites*, *timing* but not *loops*.

Participants understood and applied a variety of animation operations. While the concept recognition test helped us measure change in knowledge of common concepts, it cannot determine in-depth understanding and application of animation. Therefore, we also analyzed the animations developed by the participants in the Open-ended Task to see if they understood the animation operations enough to utilize in their own creations. All but one participant in this task created animations with 1 scene (P3 used 2 scenes), while the number of keyframes varied from 6 to 18 (μ = 11, σ = 3.9). The number of sprites used by the participants also varied from 1 to 5 (μ = 2.5, σ = 1.5) and the total number of sprite cels (across all the sprites) created also had a wide range from 2 to 15 (μ = 6.3, σ = 4.15). In terms of the animation operations utilized by the participants, all 9/9 used *translate*, 8/9 used *rotate*, while only 1/9 used *scale*. 5/9 participants had their characters *appear/disappear* in their animation and 1/9 used the *set timing* and *repeat motion* operations. The complexity of animations created by the participants in the number of keyframes, sprites, and sprite cels used showcases their ability to independently create complete animations with Cartoonimator. As evidenced by the animation operations used, all the participants had become comfortable with using the *translate*, *rotate*, and *appear/disappear* operations.

Even though only a few participants used the more advanced operations of *set timing* and *repeat motion* operations, others also noted in the interview that they learned about those operations but didn't need to use them in their animation. Overall, when reflecting on their interaction with the tool, all the participants agreed that they learned something about animation through this experience, even if they had prior exposure to animation. From participants' responses about their process of animation in the open-ended task, we observed that many participants decided on their animation idea because they wanted to explore certain animation operations that they learned about in the previous task. P5 came up with the story of a hiker climbing a mountain because they wanted to try out *translation*, while P7 wanted to see how the interpolation of *scale* looked in the animation, so they created a ski resort with skiers growing in size as they come down a mountain. Both P1 and P2 wanted to explore *defining cels* of a character and created animations centered on a character changing its forms—P1 animated a shell open and close to let a mermaid out, while P2 created a bouncing cat that squashed and stretched as it bounced on the walls. P6 was excited by the *loop* feature and created a never-ending loop of a skateboarder going back and forth. Such directed explorations of animation operations are a testament to how Cartoonimator provides a scratchpad to learn and experiment with different animation concepts.

4.4.3 RQ3: Developing interest in animation and sustained use. **Cartoonimator was fun and engaging for participants.** Based on the statements in the post-survey, we see that participants mostly "enjoyed interacting with Cartoonimator" (μ = 4.6, σ = 0.5) and would also be "happy to use it regularly" (μ = 4.1, σ = 0.6). They also strongly agreed that they were "focused while interacting with Cartoonimator" (μ = 4.7, σ = 0.4). In the interviews, 8/9 participants remarked how animating with Cartoonimator "was really fun". P7 rated the experience as *"10/10"—"I liked it. I thought it was really fun. I don't really do stuff like that, so it was fun to do and you can literally do anything, so I thought that was cool!"*

Creating with Cartoonimator positively affected participants' interest in animation. In this evaluation, we wanted to study how interacting and creating with Cartoonimator affects participants' interest in and perceptions of animation. From the pre- and post-questionnaires, participants' agreement to the statement "I find animation interesting" went up significantly from μ = 2.6 (σ = 0.86) to μ = 4 (σ = 0.86) with a P-value of 0.004 ($p < 0.05$). Compared to existing animation tools and software that could be "intimidating" (P1) and "tedious" (P8, P9), Cartoonimator seemed to ease the participants' apprehensions about animation—*"I wouldn't, in general, spend a Thursday afternoon animating. But this [Cartoonimator] felt definitely very low-barrier for me"* (P1).

Participants want to continue using Cartoonimator. After interacting with the tool, most of the participants were interested in using it more—*"I think now that I know how it works, I can do cooler stuff with it"* (P8). They see themselves animating with Cartoonimator as a hobby (P5, P7), an activity to do with kids (P1), or for quickly prototyping visualizations for other things (P6, P9). *"I could make fun little videos to send to people for their birthday, if it's this* *easy"* (P5). In the post-questionnaire, we also found participants' general agreement to the statements "I want to learn more about animation" (μ = 3.8, σ = 0.78) and "I want to create more animation in the future" (μ = 4.2, σ = 0.83).

Cartoonimator would be an engaging activity with kids. Participants saw this as a fun "family time activity" (P1) appropriate and fun for kids to introduce them to animation. P7 remarked, *"I imagine my little cousins using it... I wish I had something like this when I was a kid, it's really cool!"* (P7). They found the tool easy enough and fun for even young children, *"my nephew, who is two, and I could do this together and really enjoy that"* (P1). The tangible interface, especially, makes it more accessible for children—*"professional animators would know how to use the mouse really well, but probably not 10-year olds; this introduces the concepts really well"* (P2). The participants noted that Cartoonimator can be a fun way to introduce and develop interest in animation for children.

5 Workshop Case Studies with Children

In order to study how children interact with Cartoonimator, we conducted three play-testing workshops at a youth summer camp with a total of 21 children between the ages of 6-10 (μ = 8.05, σ = 1.25). In these group workshops, we examined if the children are able to learn how to use Cartoonimator to create animations, and sought to understand their engagement and creative exploration with the tool. The workshops were conducted at a summer camp setting in the US Mountain West over three sessions, comprising a total of 21 children and different children in each session. The distribution and ages of the participants across the sessions are described in Table 4.

Table 4: Distribution of participants and their ages across the three workshops.

W1	C1	C2	C3	C4	C5	C6	C7					μ	σ
	10	8	7	10	9	10	7					8.71	1.38
W2	C1	C2	C3									μ	σ
	7	8	8									7.67	0.58
W3	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	μ	σ
	8	8	6	9	6	8	9	7	6	9	9	7.72	1.27

5.1 Procedure and Data Collection

All three workshops shared a similar structure and ran for about two hours. We first introduced the activity of animation to the children by describing it as the technique to create their favorite cartoon shows and then demonstrated how they can create their own cartoon animations with Cartoonimator. We explained common animation terms used in the kit like *scene*, *keyframe*, and *sprite*. After the introduction, children were asked to create their own animations with the support of workshop facilitators. In workshop 1 (W1), this consisted of open-ended play. In workshop 2 (W2) and workshop 3 (W3), students were first asked to complete simple tasks designed to scaffold the usage of the tool and the possible animation operations. These five tasks involved animating a character to move on a path printed out on a scene sheet (Fig. 8), and were designed to be simpler than the Recreate Task in the system evaluation with adults. In W1 and after completing the tasks in W2 and W3, the children explored the kit in an open-ended manner—coming up with their own stories and characters, and drawing out the backgrounds and sprites themselves. In these workshops, the children worked with Cartoonimator templates printed on a standard letter (8.5"x11") scene sheet and 2.5" object cards on which they could draw their own characters and backgrounds. We also provided some animal characters already printed on the object cards. Since this was a group setting with young children, we did not keep the option of obtaining assets from the internet and printing them as that would have been challenging for the facilitators to manage.

Throughout the workshop sessions, we documented our observations as qualitative field notes, captured pictures of the creations, and downloaded all the animations created by them on Cartoonimator. In our notes, we transcribed any communication by the participants that reflected their experience, thought process, and meaning of their actions. After the workshops, we also interviewed the camp counselor—an experienced educator who observed the workshops—in a semi-structured manner about their impressions of the kit and how they might see Cartoonimator fit into their educational programming.

The research team qualitatively analyzed the observations and the counselor interview along the themes of **learnability**, **engagement**, and **creativity**. To find evidence for **learnability**, we looked for indicators of how the participants were able to learn the usage of the kit and create animations with it. For **engagement**, we focused on behavioral measures of engagement, such as whether the children liked interacting with the Cartoonimator kit and wanted to continue using it. To investigate whether the participants were being **creative** in using Cartoonimator, we considered the "Little-C" or personal definition of creativity [18] and observed the participants' development of imaginative and novel ideas through the means of Cartoonimator.

These workshops were intended to be a preliminary investigation of children's use of Cartoonimator, which will be followed by a formal evaluation of their animation learning and interest development in our future work. Observations of the children's interaction with the tool supported by the interview with the camp counselor helped us gain insights into children's use of Cartoonimator in the broader context of their everyday activities and behavior. We present these learnings as case studies of Cartoonimator workshops categorized by the themes discussed above.

5.2 Findings

5.2.1 Learnability. **Children easily learned how to use Cartoonimator and then created animations with it.** Once the kit had been introduced at the beginning of the workshops, they were excited to try it out and felt confident to experiment and create animations themselves. This shows that the kit is approachable and has low floors for even the youngest of children to jump right in. We observed the children engage with inquiry and critical thinking while interacting with Cartoonimator—they were thinking (sometimes out loud) about "what will happen if I do this vs that", or "how can I make this idea work", or "why is this not working". As remarked by the counselor, this type of inquiry is essential in an

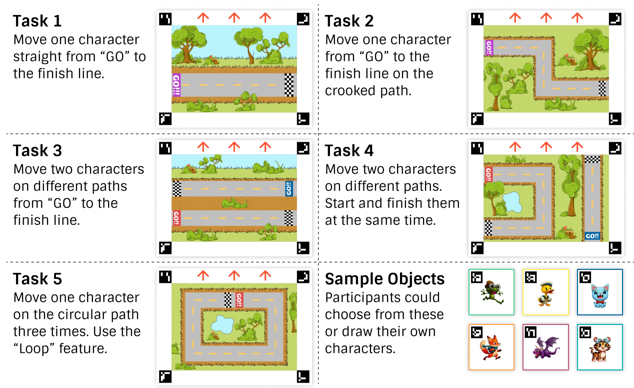

Figure 8: Workshop tasks to scaffold Cartoonimator features: basic animation with translation and rotation(tasks 1, 2), multiple characters (tasks 3, 4), and loops (task 5). Sample object cards available for children to use (created with the help of Bing AI [9]).

educational tool and shows promise for Cartoonimator's use in educational settings.

However, as with most tools for children, scaffolding is essential. In the first workshop with the open-ended format (W1), we observed that while children were able to independently create animations with Cartoonimator, most of the creations were simple and didn't utilize many of the features of the tool. For example, most animations had a single character and only straight-line motions. This could be due to the short duration of the workshop (2 hours), but it might also have been because the full potential of the kit was not made more clear to the children. Leveraging these insights, we added specific tasks in the second and third workshops to gradually introduce the features of the kit. In W2 and W3, the children were able to complete all of the tasks within the time, and further created their own animations that were longer and more complex.

5.2.2 Engagement. In all the workshops, we observed signs of engagement and enjoyment from the children—**they were focused on completing the tasks and creating their own animations.** The camp counselor informed us that many children were talking about the activity for days after the workshop and wanted to do it again. According to the counselor, *"Some would have been happy to interact with it all day"*. The counselor also noted that W3-C3, who had been known to be extremely talkative and always distracted by their own thoughts, was completely quiet and focused on working with Cartoonimator—an indication of how engaged they were.

As a CV-based system, Cartoonimator often resulted in animations with some strange artifacts and glitches due to external factors like lighting conditions (further discussed in section 5.3.3). While these bugs were discouraging, we were encouraged to see how the children were mostly accepting of these challenges. They were not easily frustrated and were motivated to continually try and fix issues, either by recoloring their drawings, or being more careful while capturing. One specific example brought to our attention by the camp counselor was of W3-C7, who was known to be a perfectionist and irritable when things didn't work. Working with Cartoonimator, however, W3-C7 was very patient and satisfied with what they created, despite having experienced numerous glitches with the system from the beginning. W3-C7's willingness to work through these technological challenges demonstrates how thoroughly engaged they were with Cartoonimator.

5.2.3 Creativity. Throughout the workshops, **we observed the children being creative with Cartoonimator, either with what they were creating or how they were creating it.** In the open-ended portion of the workshops (all of W1 and post-tasks in W2 and W3), they created their own stories and built animations to portray them. These included a "fish-car" going on a journey, ghosts blowing away a person's candle in the night, or a caterpillar saving a princess from a dragon's castle. Children have all kinds of stories, and they were able to use Cartoonimator to build and present them.

Even in the predefined tasks, we saw children add their own characters or uniquely modify the prescribed movements, showcasing their creativity. One child included a secondary character jumping while the primary character moved on one of the paths. Another child added extra rotations and movements to their character to make it *"crazier and crazier after each loop"* (W3-C1). This shows the advantage of the flexibility that the paper-based format of Cartoonimator allows from the very beginning, which is different from many other task-based educational tools with preset solutions (e.g. LightBot [23]). Section 6 further discusses the creative opportunities offered by the paper-based interface of Cartoonimator.

6 Discussion

6.1 Tangible Interface for Animation

Cartoonimator provides a tangible interface to keyframe animation. As with other tangible interfaces, Cartoonimator is based on a more natural interaction of picking and placing characters on a scene compared to using a mouse in a software. This interaction felt very intuitive and welcoming to the participants in the study and the workshops. Further, the tool allowed for more direct and open expressivity by enabling the users to draw their scenes and characters for their animation on paper, which they iterated on while building the keyframes. Although many software animation tools also provide a canvas to create your characters, many adults, and especially children, aren't as comfortable with illustrating in software as by hand and often resort to using pre-built assets. Cartoonimator, on the other hand, offers greater and more approachable flexibility to create animations with both hand-drawn and pre-built illustrations.

The paper-based interaction with Cartoonimator also helps animators visualize and plan their animations even before picking up the phone. We noticed many participants traced the planned movements for their characters on top of the scene before starting to capture the keyframes with the phone—the tangible interface helped guide and debug their creations in the physical space. The participants liked using their hands and engaging in what felt like a craft activity instead of a software one; they were happy to not have to primarily use their phones. With paper, users are also more eager to scratch over and start again when things don't go as they expect—it felt *"low-stakes"* (P1) and *"you can start over really quickly"* (P2).

Figure 9: Pictures of the unique ways participants utilized the paper-based tangible interface of Cartoonimator. (A) Utilizing four scene sheets to capture the wooden table as the scene background. (B) A sprite spanning two object cards. (C) A character made up of multiple object cards put together to animate different parts of the character separately. Small graphics on individual cut-outs (e.g. pipe) to move around across the sprites. (D) Using object cards to create a dynamic scene background where a guard appears and disappears from a castle window. (E) Using the translucency of paper to trace out multiple sprite cels. Pictures A, B, D are from the workshops with children, while C and E are from the system evaluations with adults.

We further posit that the tangible interaction for constructing the animation is conducive to learning about and applying animation concepts and operations. As we observed in the study, most participants utilized *translate*, *rotate*, and *appear/disappear* in their animations. These animation operations in particular have a direct mapping in users' tangible interaction with the Cartoonimator—they physically move the object cards on the scene to define keyframes with these operations. The interface also supports *defining cels, morphing* through swapping of the object cards, and further makes it easy to define cels through the translucency of paper. P4, P8, and P9 noticed this (on standard 100 gsm paper)—P8 and P9 created accurate copies of the sprites for different cels by placing one object card over another and tracing (Figure 9E), while P4 used that to place their duck sprite exactly on top of the water level.

The tangible interface of Cartoonimator supports a sense of creativity and problem-solving in using the tool itself to suit varying animation needs. For instance, many participants asked, how can we create non-square-bound characters with Cartoonimator? In one of the workshops, a child wanted a bigger character in their story than was provided, and they came up with the idea of putting together two different object cards and drawing a character spanning both cards (Figure 9B). They always moved both the cards together such that it was functionally one big character. Similarly, P9 thought of creating a tall bar for their bar chart by placing two object cards together. They animated the bar chart getting shorter by hiding the top card behind the bottom card over successive keyframes. While this need to add bigger characters is itself an artifact of a tangible interface, we see how Cartoonimator allows for space to innovate and come up with interesting ways to achieve users' animation goals.

Given its physical nature, Cartoonimator is also not limited by its paper templates. We have designed the tool to be forgiving of how things in the real world are captured with the help of CV techniques—as long as the camera can see the four corner markers of a scene sheet, and the one marker on an object card, it will capture and build the animation. This quality of the system was discovered and "exploited" by some participants in the study and workshops to use Cartoonimator in ways we had not expected or designed for. W3-C8 and their friends in the workshop set out with a goal of incorporating real objects in their animation instead of drawing. Playing around with the scene sheets, they discovered that if they placed four sheets such that only one corner is visible from each (Figure 9A), they would be able to capture the wooden table itself for the background of their animation. They further discovered the importance of the marker on the object card, and cut it out to place next to real objects and have them appear in the animation—first, a toy wheel, then their own hand. P8 in the study wanted to create a big Homunculus character spanning multiple object cards to move different parts of its body independently (Figure 9C). While testing it, they realized that it's better to have some parts be stationary, so they simply cut those out from the object card (e.g. the torso) and pasted them on the background. Their character had a pipe that they wanted to move from its hand to its mouth, which normally would have taken several cels of both the face and the hands. Instead, they cut out the pipe on a small piece of paper and moved it freely between keyframes to capture the intended movement.

These "unintended" uses of Cartoonimator showcase the flexibility and ease of experimentation offered by a paper-based interface. Users are more likely to tweak a tool to meet their needs if they feel that it is welcoming and accessible. They are empowered to explore the technology—they are not intimidated by it, but instead are encouraged to tinker with it, and even expand the capabilities of the tool itself.

6.2 Animation and Cartoonimator in Daily Life

Through the system evaluation and the workshops we conducted, we found that Cartoonimator provides an engaging and accessible introduction to animation. The keyframing technique central to using Cartoonimator made the process of creating animation quicker and less intimidating to participants than sophisticated animation software. Users found the paper-based interface of the tool welcoming because paper is a more familiar and malleable material, and the activity feels like craft instead of something professional. The workshops also helped us demonstrate how Cartoonimator is designed to be used in real educational and practical settings. With such a low barrier to animation and a robust, easy-to-use system, Cartoonimator is something we hope to see people use for different purposes and interests.

In our study, participants mentioned that they would like to interact more with Cartoonimator and create small animations with it. They saw it as a fun hobby and something to work on with kids. They found potential in Cartoonimator in DIY activities and creating gifts for people. Some participants also noted the quick nature of animation with Cartoonimator and thought about its use as a prototyping tool for different contexts. For example, P9 created an animation of a changing bar chart, which was relevant to their field of data visualization. They remarked that although the fidelity of Cartoonimator animation wasn't high enough for accurate data representation, it can help create quick representations of dynamic data and for educational purposes. P2 and P4 both had some prior experience with animation and work in the adjacent fields of game design and VR—they also saw Cartoonimator as a helpful tool in quickly mocking up animations or effects that can then be built up in appropriate software.

In our exploration of children creating with Cartoonimator, we observed that it was an accessible tool for children to tell their stories. Animating with Cartoonimator is an activity we see parents or educators doing with kids to enrich their storytelling sessions and improve their reading comprehension. Given the ease of use and resilience of the tool, the Cartoonimator kit can also be used in classrooms to varying degrees. In our workshops, we used smartphones as the primary device for Cartoonimator; however, the kit is also compatible with other mobile devices like tablets, which have become increasingly common in K-12 schools in the US. In a classroom, the teachers could quickly build an animation with Cartoonimator to demonstrate a science concept and engage the children, e.g. projectile motion of a ball, or an animation showing the lifecycle of a butterfly. Teachers can also provide prepared templates to the children and have them animate using Cartoonimator to demonstrate their understanding of a concept. Our future work will explore how teachers and educators use Cartoonimator in different educational settings, and understand how it might benefit students' learning.

6.3 Challenges and Future Improvements

Throughout the evaluation studies and workshops, we also observed interaction challenges when working with the Cartoonimator system. The biggest issue was images not showing up in the animation as the animators expected them to. In CV-based systems, a number of external factors affect the detection of objects. We observed that with imperfect lighting, or because of motion blur when the camera was moved, the markers weren't detected appropriately and the objects wouldn't be recognized to appear in the animation. The participants also noted that the app did not provide enough feedback about what objects were detected and if they were captured completely. Further, the background subtraction done on the sprites led to the elimination of light colors and thin line drawings. Such issues often led to disappointment in both children and adults alike, as the work they put in didn't give a result. In interaction with the app, some participants also found it challenging to keep mental track of the last keyframe as they moved the objects and captured the next keyframe so that they could replace the objects appropriately. Considering the design of the system itself, we often observed that participants found it challenging to work with many object cards on the scene, such that they don't overlap with each other and interfere with the detection.

Based on the feedback from the participants, we plan to address all these challenges in upcoming versions of the system. We will provide better feedback about the characters captured in a keyframe by showing how the frame would look exactly in the system. This can help the users detect and fix the CV-based bugs earlier in the creation process. To help with tracking the last keyframe while creating the current one, we are exploring an idea put forward by P2 about showing "ghost" images in the camera view, which would be a mostly translucent overlay over the camera that a user can use as a reference while placing their objects. To address the challenge of many objects on a scene, we plan to conduct further user testing with objects of many different sizes and improve the detection of the object markers in the system.

For future versions of the system, we are also exploring feature suggestions from the participants. P2 and P4 had ideas about advancing the animations of single characters in a complete animation through isolated control and looping—instead of looping a full scene, what if a certain motion of one character could be looped while others stay the same? P4 had the idea of supporting "motion effects" or minor graphics added to an animation such as blowing of wind around a character, or slight alteration of a character without needing to draw a whole other version. Keeping in line with the paper-based, everyday material format, we are considering small transparent sheets that can be layered on top of object cards to add effects and variations. Given the relevance and the current Artificial Intelligence landscape, P1 suggested integrating AI image generation tools into the system to make the process of adding digital scenes and characters more seamless. These are some of the additions we are experimenting with for future versions of Cartoonimator, alongside working with teachers to explore the kit's use in various educational settings.

7 Conclusion

In this paper, we presented Cartoonimator, a paper-based kit for animations. The kit consists of paper templates to draw or print scene backgrounds and characters for the animation, and a smartphone web app to capture keyframes and view the animation. Cartoonimator provides a tangible interface for children and adults to create animations from their drawings using the keyframe animation technique and enables 10 types of common animation operations. We conducted a system evaluation with adults to investigate how they interact with the tool, whether they learn about animation concepts, and how it affects their interest in animation. Our findings show that Cartoonimator is an easy and welcoming tool for animation, and it helps users learn about and apply animation concepts. They see Cartoonimator as a fun hobby, as well has a helpful tool to prototype animated illustrations. We also conducted three play-testing workshops with children and found that children as young as 6-10 years were able to create animations with it and were greatly engaged in the activity. Our findings from the evaluation and the workshop help us understand the implications of using a paper-based tangible interface for creative applications like animation. Finally, these sessions helped us determine the benefits and challenges of the Cartoonimator system, and uncover future directions for the project.

As a whole, we demonstrate that Cartoonimator is an approachable, paper-based tool for keyframe animation. We have made the Cartoonimator kit open-source and publicly available[7], and we hope to see children and adults use it for animation for learning, work, and play.

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