Sand Playground: Designing Human-AI physical Interface for Co-creation in Motion

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Figure 1: A user is drawing on the sand playground, and the metal ball draws synchronously.

ABSTRACT

In this paper, we investigated the potential of using a tangible interaction interface for creative activities as a preliminary step to achieve human-AI co-creation. We conducted a preliminary study to explore sand as a medium for co-creation and identify potential opportunities of AI mediating the process. We created Sand Playground, a co-creation interface that uses sand as an interaction medium. We describe details for building the interface. We selected two opportunities from the study and developed them as two modes, Artistic Mimicry and Zen Garden. We also conducted a workshop study using Sand Playground to evaluate collaboration and the characteristics of the tangible interface. We identified findings responding to drawing strategies, multisensorial experience, and performative and ephemeral quality of creation. We discuss next steps of achieving our ultimate goal: an AI-mediated interface that collaborates with users physically in real-time on sand.

CCS CONCEPTS

• **Human-centered computing** → **Collaborative interaction**; **Collaborative and social computing devices**; Empirical studies in HCI.

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KEYWORDS

Creativity Support, Embodied Cognition, Tangible User Interfaces, Co-creativity

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1 INTRODUCTION

The practice of leveraging Artificial Intelligence (AI) in creative activities such as design, music, and architecture have grown over the past half-century. The degree of agency of each intelligent system has ranged from full control, to a partnership, and to an apprenticeship. In drawing activities, several creativity support tools that enable human-AI co-creation were built for two-dimensional digital screens. However, tangible interfaces have enabled physical embodiment [11], and many researchers and designers have applied physicality and material-centered interaction design in their investigations [6, 18, 20, 21]. Other researchers and artists have explored using robots as a physical AI agent to draw or paint collaboratively with a user on paper [1, 12].

In this paper, we introduce Sand Playground to extend the work in human-AI drawing practices beyond two-dimensional digital surfaces (Figure 1). Sand Playground is a co-creation interface that uses sand as the interaction medium. Our primary goal is to develop grounded interactions and a technical workflow to achieve human-AI co-creation. We focus on building toward a human-AI co-creation process as a conversation in a physical medium [4]. In the scope of this study, and to investigate the needed interactions, we ask:

how is sand being used as both a medium and tool for a creation? What interactions emerge when users interact with a malleable and intuitive canvas such as sand?

To investigate these questions, we applied a Research through Design approach (RtD) [22]. We started with an exploration and a preliminary study of ways of co-creating with AI on a physical three-dimensional medium. Based on our preliminary findings, we chose sand due to its malleable, easy to reset characteristics, and its immersive quality as compared to drawing in standardized screen-based software. Sand is a material that is both affordable and easily obtainable. Drawing on sand is one of the oldest intuitive practices, and humans of all ages draw and form shapes on sand when found. It has also been a meditation practice in many cultures for centuries [14]. Contemporary artists also create sand art for aesthetic practices and experimental pattern-making [10].

We conducted a preliminary study to identify potential AI-mediated co-creation activities on sand and subsequently focused on collaborative drawing. We created a research prototype, Sand Playground, and conceptualized two interaction modes that support collaborative drawing. To discover potential qualities influencing human-AI collaboration, we conducted a qualitative study to evaluate both the aspects that could influence human-AI collaboration and the critical characteristics of designing the tangible interface. Our early findings confirmed that the process of drawing on Sand Playground is easy and explorative, and the experience provided engaging sensory feedback as well as a performative quality. The characteristics of sand, including "multisensorial", "performative", and "ephemeral", affected both the process and outcome of such co-creation. We further discussed human-AI co-creation via embodied interactions, specifically by leveraging AI models and algorithms in generating novel (drawing) strokes, which was limited by the current setup.

The contributions of this paper are:

- A newly introduced tangible interaction interface for creativity support that can be used for further human-AI co-creation research.
- An evaluation of this interface.
- An exploration on potential human-AI co-creation activities on tangible mediums.
- Identification of future applications in human-AI co-creation using this interface.

2 RELATED WORK

In this section, we discuss existing research and related works on tangible co-creation systems, computational interactions on sand, and the interactions and workflows in co-creation.

2.1 Tangible Co-creation Interfaces and Systems

Current research on human-AI co-creation in visual mediums mainly focuses on studying two-dimensional drawings through angles like measuring the creativity feature of a designed system, or analyzing the roles of communication and interaction [2, 9, 13, 15]. Most of the human-AI co-creation research in the design field has emphasized drawing automation and completion on 2D screens [5, 9, 15]. For example, Collabdraw was introduced as an online platform where a user could draw a specific drawing, and the AI system would complete the drawing from a limited data set [5]. Besides drawing specific objects, based on the concept of "Casual Creators," Davis et al. [2] created Drawing Apprentice, a sketching tool that generates open-ended creation with users. The authors investigated the participatory sense-making process in human-AI collaboration and analyzed improvisational collaboration through abstract drawing on a digital canvas.

These systems are usually designed to emphasize the co-creation experience instead of producing a highly detailed outcome. However, there has not been enough research on human-AI collaboration and interactions on tangible interfaces. Researchers have shown that tangible and physical co-creation interfaces produce more effective experiences [8, 15]. Lin et al. [12] introduced Cobbie, a co-creator bot that could be used in early design ideation phases for sketching together with users on paper. Compared to digital screen-based interfaces, physical AI agents are more successful for artistic exploration. Their research demonstrated how several human modalities in co-creation can support embodied interactions for co-creation.

2.2 Computational Interactions on Sand

Existing works have explored possible applications of sand for computational interactions. AR sandbox [16, 17] leverages the shape-changing ability of sand by applying direct manipulation of the material, assisted with projection mapping for displaying 3D information directly onto the sand landscape. Additionally, researchers [3] have explored using a sand table as an ambient display for visualizing information. The sand display reveals spatial information such as moving patterns of passersby in the hallway and noise level. Moreover, there are projects that utilize sand for creating kinetic art by motions of pattern creations. In project Sisyphus [7], the motion of its drawing agent is generated via algorithms or pre-produced designs. However, these research and projects are mostly encoded with predefined parameters and limited user controls.

To further investigate the materiality and medium characteristics of sand, we reviewed various types of artistic creations on sand and to understand people's creative intuition. Michael Welland [19] discusses in his book, Sand: The Never-Ending Story, the history and properties of using sand as a creative medium. People would use hands, fingers, objects, and other tools to play with sand. Some enjoy the process of just playing with sand rather than achieving an artistic piece. People would also draw over existing works on sand and recreate upon it. The type of creation can be broad, in addition to drawing 2D strokes, written letters, or patterns, people would also create 3D shapes on the surface like sandcastles or sculptures. Lastly, the process of creating on sand can be performative, with rhythms, sounds, and speed variations, and has been specifically observed in professional and cultural-related works [19].

2.3 Interactions and Workflows in Co-creation

Researchers have investigated human-AI collaborative creations through angles including observation, recollection, and imagination [8]. Apart from the Drawing Apprentice [2], improvisational co-creation and free-form open-ended drawing are less explored. Based on analysis of interaction workflows from other research

and existing works, considering both the interactive aspect of co-creation and medium characteristics of sand, we decided that the workflow for our research should consist of: a) Improvisational actions and continuous drawing, and b) process-oriented creation.

3 STUDY DESIGN

Based on the analysis of related work, we concluded the primary characteristics of creation on sand are: **multisensorial**, **performative**, and **ephemeral**. The tactile feedback and subtle sound created through drawing on sand result in a sensory loop affecting the embodied interactions. Due to the medium's dynamic nature, it is possible for one to not specify the final creation outcome and change their concepts along the way. The process of embodied actions and rhythmic motions from drawing on sand can be seen as an act of performance. Lastly, since sand is malleable and could be reset and covered by new creations easily, we decided to focus on the creation process.

We designed two studies. We first explored through a preliminary study to identify opportunities for an intelligent system to aid users in a co-creation process on sand. Based on the results from the preliminary study, we proceeded with a focus on drawing activity. We further developed a prototype interface, Sand Playground, and assigned two chosen activities from the study as two interaction modes. We then conducted a workshop study for evaluating the collaboration properties and materiality affordances of the tangible interface.

4 PRELIMINARY STUDY

The preliminary study session contains a 30 minutes brainstorming workshop with 3 participants with a design and art background to ideate concepts around human-AI co-creative activities on sand. Two of the participants identified as females aged 25, 32. One participant identified as male and aged 32. All participants are graduate students with a design background. During the workshop, we asked two questions: 1) What types of creative collaborative activity could be achieved on sand between the interface and user? 2) How can the interface enable collaboration through these interactions? We asked the participants to generate as many ideas as possible within 15 minutes, followed by a group session to discuss and categorize the generated ideas. The workshop produced a list of 9 activities categorized in Table 1.

Out of all nine co-creative activities generated, we identified four as drawing activities, one as communication support, two as games, and two other types of creative activity. We selected the two concepts from the drawing activities category, Artistic Mimicry and Zen Garden to move forward, since drawing on sand is an intuitive interaction, and the two ideas encourage basic artistic strategies such as "Mimicry" and "Spatial Composition" that could be helpful for us to evaluate further.

5 SAND PLAYGROUND

5.1 Concept and Interactions

We created our research prototype as an interface to support collaborative drawing activities between a human and a machine, with the potential of adding an AI agent and achieving full human-AI co-creation on sand. We refined and proposed two interaction modes, Artistic Mimicry and Zen-garden, that covers two common artistic strategies: mimicry and spatial composition. Developing these two modes will help us to determine if sand is a suitable medium for co-creation, and in what aspects can it be supportive for such activities.

In Artistic Mimicry, the user leads the drawing sessions by directly drawing on the sand with one finger. The interface recognizes the user's fingertip position and drawing status, whether on sand or not, and responds synchronously by actuating the metal ball to be in the centrosymmetric position. In Zen-garden, users lead the drawing by placing a rock, or a group of rocks, on sand. The interface recognizes the location, the centroid, and the contour shapes of the rocks, then responds by actuating the metal ball to draw a series of concentric contours around the rocks. When the interface was in the process of drawing contours, the user could place rocks to be drawn around next.

5.2 Prototype Setup

In our setup, the user stands in front of a table equipped with an interactive sandbox. The sandbox provides the user with an interface that they could draw or place objects on. We provided a box of black pebbles as the placing objects. As the user initiates their action, the interface tracks the corresponding movement and input, and draws together with the user by actuating a magnetic metal ball in the same sandbox (Figure 2, right).

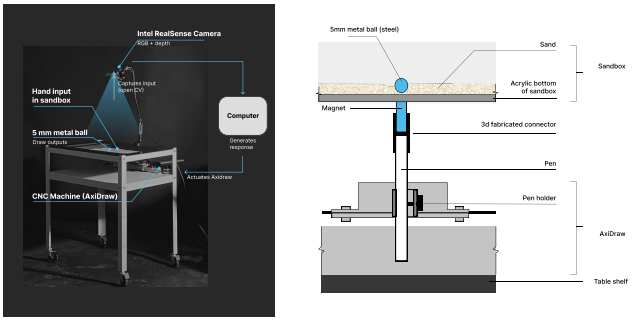

Figure 2: Sand Playground. Left: system setup of Sand playground. Right: A close-up on the prototype section

5.3 Technical Implementation

The input and recognition of the user's movements are detected by an Intel Realsense camera, with both RGB and Depth video streams, mounted on top of the sandbox. Using OpenCV and the Google MediaPipe library in Python, the system detects real-time coordinates of the user's index fingertip or the centroid and contours of the placed pebbles. Using the depth stream, the interface then evaluates if the hand is effectively drawing on sand or just hovering above the sand (Figure 3).

We took inspiration from previous research and projects for the output [3, 7]. The interface uses a metal ball (d=5mm) as the agent for outputting drawing strokes. The metal ball is actuated by a piece of magnet underneath the sandbox. The magnet is connected to a pen through a 3D printed connector. The pen's location is

Table 1: List of generated concepts of human-AI co-creativity on sand

Activity	Description	Role of AI	Workflow
Drawing: Artistic Mimicry	Interface imitates the user's input and output with variations (e.g., scaling, reflection, rotation	Imitation	Synchronous
Drawing: Zen-garden	User places several objects on sand, and the interface draws around these objects	Collaboration	Turn-taking
Drawing: Sketch Completion	User presents a drawing goal (e.g., drawing an apple), and interface finishes the drawing	Content Generation	Turn-taking
Drawing: Line-linking	User draws out several dots on the sand, and interface creates an optimal route that connects all of them	Completion	Turn-taking
Game: Tic-tac-toe	User and Interface play tic-tac-toe	Competition	Turn-taking
Game: Scavenger Hunt	User places several objects on sand, and interface tries to collect them by pushing the objects to a designated place	Collaboration	Turn-taking
Communication: Remote Presence	Interface acts as a mediating presence for a remote user's input and collaborates with a local user	Presence Representation	Synchronous
Others: Calligraphy Learning	User writes calligraphy on sand, and interface helps refine and evaluate the results	Content Generation	Turn-taking
Others: Completing Poem	User writes a word on the sand, and interface completes with a novel phrase	Content Generation	Turn-taking

controlled by an AxiDraw V3/A3 drawing machine. The AxiDraw is a CNC drawing machine with an 11 inch x 17 inch plotting area. It provides basic XY moving and controlling that can be customized through computational outputs.

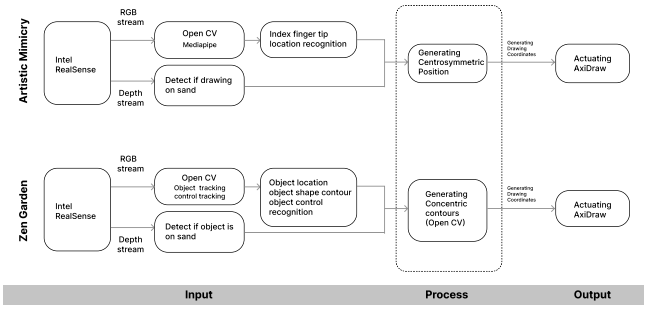

Figure 3: Workflows of the Sand Playground interface for Artistic Mimicry and Zen Garden.

6 WORKSHOP STUDY

Our study includes a workshop to test and evaluate the prototype with 2 modes, followed by a semi-structured post-workshop interview to harness qualitative evaluation of the Sand Playground.

6.1 Participants

We recruited 7 participants (3 males and 4 females) by sending out emails to students and faculties within our institution. Their mean age was 27. All the participants had experience in creative practices in Art and Design. Four of seven participants have interacted with the Sand Playground for the first time, and three out of seven participants had previous experience with the Sand Playground. Each participant joined a 30-minute workshop and a semi-structured interview session. Upon completing both the workshop and the interview, each participant received a $15 gift card as compensation for participation.

6.2 Process

We prepared the workshop to test the two interactive modes in our lab. A complete workshop session for one participant includes two warm-up sessions, one for each mode, and six creative sessions, three for each mode. Each participant spent 15 minutes completing the workshop. In the warm-up, participants were guided and given instructions to understand the intentions of the mode and physical limitations of Sand Playground. In the creative session, participants were given an open-ended prompt to collaborate and create a drawing within two minutes. They were also encouraged to think out loud during their creative session.

6.3 Interview

For each participant, we conducted 15 minutes of semi-structured interviews with 13 questions for qualitative evaluation of participant experience of Sand Playground. At the end of completing the test sessions with two modes, the participants were asked questions structured around investigating the participants' perception of collaboration with the interface, to evaluate the multisensorial, performative and ephemeral aspects of the experience, and how they affect the creation process.

7 FINDINGS

We report below our findings gathered from interview responses, observations during the study, and recorded video footage. We used a qualitative method to evaluate the set of characteristics we proposed for creating on sand with a small sample size of user-study participants. The results are framed as the conclusion of this study, and a stepping stone to further explore potential human-AI co-creation activities on sand.

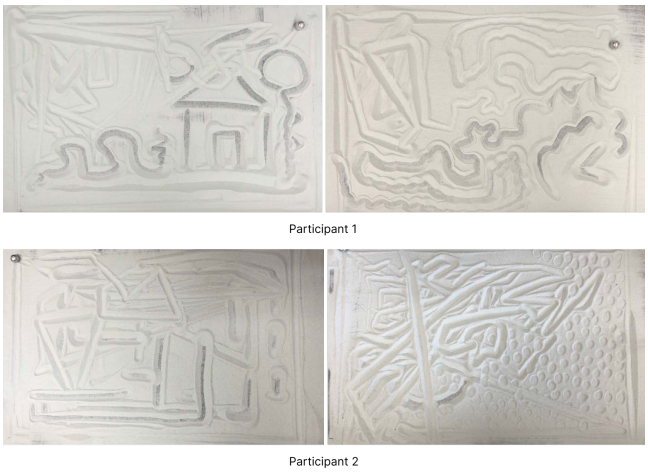

Figure 4: Comparison of drawings from two participants in different rounds. Left 1st round of drawing. Right, 3rd round of drawing

7.1 Achieving Collaboration

Participants gained awareness of the interface's intention and physical limitations through trial and error. The limitations of the interface were described as: 1) *"unstable recognition"*, 2)*" continuous lines only"*, 3) *"limited drawing speed of the metal ball"* and 4) *"fixed output line width"*.

Participants adjusted their drawing strategies to achieve better results (Figure 4). For example, in Artistic Mimicry, some participants changed their drawing speed and style to achieve different types of outputs. For instance, P3 drew continuously for better mimicry results, and P1 changed to drawing dots for a contrasting creation result (Figure 4). P2, P4, and P6 adjusted their drawing speed to produce different patterns with the metal ball, specifically P2 explained that: *"I realized that when I draw very slowly, the mimicry was very accurate. But when I drew faster, the lines became simplified, so I used that to create different patterns"*.

While most of the participants devised collaboration strategies with the interface, some identified the barriers that negatively affected their co-creation experience. First, some participants did not fully understand the intention and physical limitations even after their warm-up session. P5 said: *"I didn't get how the machine worked around the rock and how it responded to random allocation of the rocks in the second session."* Second, in Zen garden, participants mentioned a lack of motion planning. P4 suggested that: *"... I hope the system will know and avoid these rocks when it moves."*

7.2 Multisensorial Experience

In addition to visual aspects, participants reported findings related to their sensory experience. These experiences include the tactile feedback of touching the pebbles and sand, an awareness of the metal ball's movements, and the sound of the finger-sand interaction. The texture and malleability of sand positively contributed to the experience, making the process *"more fun and explorative"*. P5 and P6 said that *"I like the way my fingers touch the sand and morph it... it adds another layer to play with, compared to drawing in a screen-based app."*

Participants leveraged their proprioception by observing and then responding to the metal ball's movement and location.Some participants intentionally avoided the ball, and some intentionally created encounter moments. P5 said: *"I am afraid that I will interfere with what the metal ball is drawing, ... I will avoid bumping into the metal ball."* And P7 said: *"in Artistic Mimicry, I like the moments of crossing over what the ball draws."*

The mechanical sound produced by the AxiDraw created mixed feedback from the participants. For some participants, it acted as an indication of active drawing, but was also perceived by some as a distraction. P7 explained: *"The Sound provided hints on whether the drawing is initiated or not"*. While most of the participants were unbothered by the sound, P2 identified it as a *"spooky and weird noise"*.

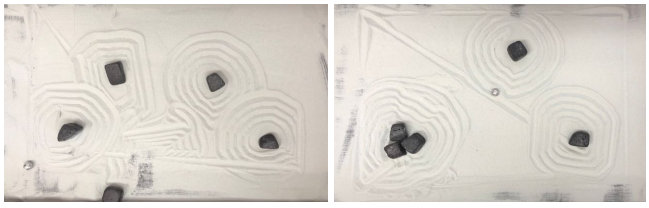

Figure 5: Two samples generated in Zen-garden

7.3 Performative Experience

Participants appreciated the dynamic spatial relationship while composing their drawings (Figure 5). P1 commented that *"It is very interesting... a different relationship was established between pebbles, sand, and my movement."* P6 said, *"It's enjoyable to just watch the metal ball moving slowly and completing a contour."*

Participants attached different personas to the metal ball (drawing agent). P3 remarked that *"It looked really cute and was playful, almost like a pet. I was trying to encourage it when it hit the*

rock in Zen Garden." P7 saw the metal ball as a collaborator and choreographed their movements accordingly: *"... I tried to end the drawing by joining the metal ball in the center by the end."*

To maintain synchronization with the interface's speed and actions in Artistic Mimicry, participants acted quickly to generate new ideas or kept drawing without concrete goals. P6 said that: *"I play the violin, and the pattern of mimicking your tutor is very common during collaboration and learning, I liked that it is reacting to my input synchronously, and it provides a more dynamic creative experience to try out new ideas very quickly."* P3 described: *"it made me keep going and drawing even though I didn't have anything specific in mind."*

7.4 Sand for Ephemeral Creation

Some participants reported a sense of *"psychological safety"* because of the ease of morphing and resetting the canvas on sand. P3 suggested that *"... I can just draw over my drawing because I like building upon what I built."* Similarly, P4 said that *"it's very easy, my drawing doesn't need to be perfect at all because it's gonna be destroyed anyway."*

8 DISCUSSION

Our primary goal in this paper is to develop grounded interactions and a technical workflow to achieve human-AI co-creation. Results from our workshop session and the qualitative evaluation method from post-workshop interviews provided insights on the co-creation experience with the Sand Playground. We focused mainly on two questions of how sand is being used both as a medium and a co-creation tool, and what interactions emerge from co-creating on a malleable medium such as sand. Based on the responses, the collaboration with Sand Playground was easy and explorative because of its tangibility and embodied qualities. The interface provides an engaging sensory feedback as performative responses. The physical limitations of the interface provided a creative output as well.

8.1 AI and creative strategy

In Sand Playground, we established an initial input–process–output (IPO) technology workflow for co-creativity on sand, which uses AI in input by recognizing and making sense of the participant's intentions. We observed the participants making sense of the interface's intention by evaluating if the response is a match for a specific creativity strategy, such as "mimicry" or "contrast" to what they have input before in the sand playground. In previous works, "mimicry" is explored in artists and researchers' work [1], but the sense-making process of other creative strategies such as "contrast" is less explored.

8.2 Sand Playground is easy to collaborate with

Sand playground is easy to collaborate with in three aspects. First, it was easy to understand the intentions of the interface. The participants paid attentions to the motions of the drawing agent and attached different personas to make sense of the intentions, just like a human collaborator. Second, it was easy for all participants to demonstrate various drawing techniques within a few rounds of creation. We observe that different levels of awareness and tolerance of the performance may be connected with familiarity with the interface; it was easier for the participants who had previous experience to apply their own strategies more quickly or test with new drawing techniques. Third, the quality of the sand being easy to reset provides "psychological safety" to try out new ideas and continue drawing.

8.3 Physical limitations as a creation tool

The physical limitations of the interface impacted the participant's choice of their creative strategy. These physical limitations included the instability of drawing recognition", the interface's inability to draw discontinuous lines, the limited drawing speed of the metal ball and the fixed width of the output line. While it could be limiting to some, other participants achieved interesting creations. They adapted to the physical limitations of the interface and leveraged these limitations as tools. This provides a great opportunity for physical Human-AI co-creation interfaces. Any interface would have its limitations, but the physicality of the interface enables using these limitations as tools.

8.4 Embodied Qualities of the interface

Similar to the findings of Lin et al. in developing Cobbie [12], the tangibility of the Sand playground made the collaboration easier. Collected responses showed positive feedback on the materiality of the interface and sand, suggesting attentions to the interaction process and its explorative quality compared to standardized screen-based drawing software. Moreover, the embodied qualities of the Sand Playground, – multisensorial, performative and ephemeral– had critical influences on the creation process. We observed that participants were aware of the sensorial feedback that engages touch, proprioception and hearing, and made drawing decisions accordingly. Both the synchronicity of performance and the ephemeral quality of sand (being easy to morph and reset) promotes co-creation with continuous engagement and exploration.

9 LIMITATIONS AND FUTURE WORKS

We identified three limitations of this study. First, AI is not yet implemented in the generation process of novel strokes (Figure 3), and the user is always leading the drawing process, thus Sand Playground cannot yet evaluate co-creation on physical medium when the user has less control. Second, we provided descriptions and instructions on guiding the participants throughout the workshop. We have not yet tested free-exploration sessions solely conducted by users themselves. Third, the workshop was conducted within a short time span and controlled lab environment. We would like to observe how the interface may be used for a longer period of time in a public place.

We believe Sand Playground has many potential opportunities to proceed with. We will explore further in the process where AI generates responses that match a unique creative strategy other than "mimicry". As a next step, we plan to expand the variety of how the interface generates drawing outcomes by using machine learning algorithms and generative models like SketchRNN. We plan to further investigate other research questions, including how humans and AI can collaborate when the AI is leading on a physical interface, and how does the user perceive the intention of the interface when the AI generates novel strokes.

10 CONCLUSION

In this paper, we introduce Sand Playground, a novel tangible interface to support computational co-creative interactions on sand. We focused on establishing initial collaborative drawing interactions and technical workflows to further develop and evaluate whether sand can be used as a medium and tool for human-AI co-creation. We harnessed the perceptions and behaviors of using the Sand Playground through a workshop. We evaluated how the proposed characteristics of creation on sand, including: multisensorial, performative and ephemeral can affect the process and goal during co-creating with the interface. We found that the embodied and tangible qualities of the interface facilitated co-creation with the AI agent. The interface provided an engaging sensory feedback as performative responses. The physical limitations of the interface provided a creative opportunity for participants to use it as part of the co-creation process. The materiality of the sand provided a drawing medium for participants with low risk of messing up the drawings. Based on the findings we have in this study, we propose an interaction strategy and future steps to further implement AI in generating novel results, and further investigate human-AI co-creation with Sand Playground.

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