Towards Inclusive Co-creative Child-robot Interaction: Can Social Robots Support Neurodivergent Children's Creativity?

Safinah Ali
MIT Media Lab
Cambridge, USA
safinah@media.mit.edu

Ayat Abodayeh
MIT Media Lab
Cambridge, USA
ayat02@media.mit.edu

Zahra Dhuliawala
MIT Media Lab
Cambridge, USA
zahrazd@media.mit.edu

Cynthia Breazeal
MIT Media Lab
Cambridge, USA
cynthiab@media.mit.edu

Hae Won Park
MIT Media Lab
Cambridge, USA
haewon@media.mit.edu

***Abstract*—This research designs and applies inclusive child-robot interactions for collaborative creativity, where elementary school children and a social robot collaboratively create and publish picture stories. The robot offers creativity scaffolding during parts of the creative process of storytelling through social interactions such as feedback, question asking, divergent thinking, and positive reinforcement. The collaborative tasks and robot interactions are personalized for neurodivergent children's unique needs. Through a five-session user study with 32 children (ages 5–9) over 8 months, we investigate the impact of the social robot on children's exhibited creativity in storytelling over time, their creative interactions with the robot, and their perceptions of the robot as a creative collaborator. Our research revealed that inclusive design practices eliminated creative barriers for children with neurodevelopmental disorders. The robot's creativity scaffolding interactions positively influenced children's verbal creativity in storytelling, and had an influence on their storytelling creative process. After multiple sessions interacting with the robot, we observed the emergence of diverse creator styles among neurodivergent learners. We propose Inclusive Co-creative Child-robot Interaction (ICCRI) guidelines for fostering creativity in children, and accommodating diverse creator styles in complex, open-ended creative tasks.**

***Index Terms*—Collaborative robots, collaboration, creativity, assistive technology, children**

I. INTRODUCTION

Children's creativity has been known to benefit their learning and well-being [1]. Research in child-computer interaction has suggested several approaches for using technology to foster creativity in children [2]. Previous work in Human-robot Interaction (HRI) has used social robots as Creativity Support Tools (CSTs) for their embodiment, artificial creativity demonstration, and social scaffolding mechanisms for fostering children's creativity [3]–[5]. The ability to demonstrate creativity and socially interact with children pose social robots as effective collaborators of children in controlled creative tasks [2], [6]–[8]. Recent advancements in Large Language Models (LLMs) also enable robots to exhibit creativity and collaborate in creative tasks [9]. While previous work was primarily single encounter studies, set in measurable controlled creative tasks (such as a Zen garden task [10]), or was carried out with neurotypical students [3], some have shown promise in developing learning skills for children with neurodevelopmental disorders, such as robot-assisted therapy for children with Autism Spectrum Disorder (ASD) and ADHD [11], [12]. Literature on socially assistive robots for ASD emphasized on the importance of personalizing interactions for every child's abilities and motivations [12], [13]. In this work, we explore whether multiple encounters with a social robot in a collaborative storytelling task supports neurodiverse children's creativity.

We designed *Genie*, a novel co-creative digital storytelling tool that can be used by children to create picture stories. Children can use voice or visual scaffolds to record their stories page-by-page, and create images and/or drawings for each page. They collaborate with the social robot Jibo to create stories. Their creativity is supported using two mechanisms: **(1) Collaborative creation:** where the robot utilizes large language models (LLMs) to complete parts of children's story on each page, or generate images relevant to the story, and **(2) Social interaction:** where the robot uses verbal and non-verbal interactions to support children's creative expression. In order to prioritize children's agency over the story, collaborative creation is *reactive*, only offered when children initiate it. Social interaction, on the other hand, is *proactive*, where the robot offers creativity scaffolding depending on children's actions and stories. The collaborative storytelling interaction is personalized for every child's abilities. This constitutes offering multiple modalities of creation (voice, text, and visual story creation interface), different language complexities based on children's reading levels, and robot interaction patterns that support children's specific needs. We propose a set of child-robot interaction patterns, Inclusive Co-creative Child-robot Interaction (ICCRI), geared towards supporting neurodivergent children's creativity in collaborative creative tasks.

To validate these design patterns, we ran a study with 32 neurodivergent students with diverse cognitive, language, social, and physical needs. Children interacted with the system to create picture stories over a course of five sessions spread across eight months. In the first session (S0), to understand children's baseline creative encounters with Genie, children created the stories *without* the robot's creativity scaffolding interactions. In the subsequent three sessions (S1-3), children co-created the stories *with* the robot offering creativity scaffolding. To understand the sustained effect of the robot's scaffolding on children's creativity, we conducted a post-delayed session (S4), where the robot's creativity scaffolding support was withdrawn. We explored children's creativity encounters while co-creating the stories by studying: (1) the creative product: stories, and (2) the creative collaborative process: creative and collaborative behaviors expressed. Through a quantitative analysis of the verbal creativity of the stories, qualitative analysis of the user behaviors exhibited during interaction, and analyzing researcher notes, we explore how the robot's creativity scaffolding influenced children's creative product, process, and experience over multiple encounters with the robot.

To study the social robot's role in fostering neurodivergent children's creativity, we form the following hypotheses:

H1. The proposed ICCRI patterns reduce creation barriers for neurodivergent children in a story creativity task: The system reduces creation barriers for participants. **H2.** The creativity scaffolding interactions exhibited by the robot enhances neurodivergent children's verbal creativity in story creation. This effect is sustained over multiple encounters, and subsequently, in the absence of the robot. **H2.1.** Children exhibit significantly higher verbal creativity in stories in S1 as compared to the baseline S0. **H2.2.** Children exhibit a growth in verbal creativity as sessions progress. This effect is sustained in the post-delayed session without the robot's scaffolding. **H3.** The robots' creativity scaffolding interactions are correlated with children's creative actions in the co-creative process.

We report results from a 5-session study with 32 participants and discuss design implications for ICCRI in supporting diverse creative styles in open-ended child-robot tasks.

II. Background

A. Children's creativity

While definitions of creativity vary [1], [14], many adopt Guilford's conceptualization, which includes fluency (producing many ideas), flexibility (creating varied ideas), originality (generating unique ideas), and elaboration (expanding ideas) [15]. Creativity manifests in verbal forms and figural forms. Researchers distinguish the creative process (steps to reach an artifact) from the creative product itself. Sawyer described creativity as a group phenomenon involving flow, collaboration, and improvisation [16], with contributions blending into a shared outcome [17]. Factors like autonomy, good role models, and peer collaboration stimulate creativity [18]–[20], and children often emulate creative behaviors from collaborators, including robots [3], [6].

In this work, we situated child-robot interaction in a multimedia storytelling environment. Creating stories helps develop skills such as creative expression [21], social-emotional communication [22]–[25], critical thinking [26], and language-driven thinking [27]. These skills were beneficial for our participants with social-emotional learning needs, attention disorders, ASD, and verbal communication challenges. While children with ASD often have lower language comprehension, they can still demonstrate unique creative profiles [28].

B. Social robots for creativity support

The decline in children's creativity has driven the development of various technological approaches to stimulate creative thinking [2], using tools like robotics kits [29], games [30], and conductive ink [31]. Social AI agents, such as social robots, have also been used to inspire creativity through social interaction and imagination [4], [6], [32], [33]. Social interactions make robots effective creativity partners. While the robot's presence alone does not significantly impact creativity, studies show that social scaffolding behaviors enhance children's creative expression [2], [3].

Previous work focused on structured tasks with neurotypical children and lacked exploration of long-term, open-ended interactions [3]. Alves-Oliveira et al. demonstrated the effectiveness of robots in verbal and figural storytelling [34], while Ligthart et al. showed that reenacting stories and adding sound effects enhanced attention and enjoyment [5]. We extend this literature by focusing on neurodivergent children, using an open-ended verbal and visual storytelling task where students have full agency over the story's content and the robot's role. Our study investigates the impact of personalized child-robot interactions on children's creativity over multiple encounters.

C. Inclusive child-robot interaction

Previous work in inclusive CRI involved social robots playing the role of collaborative storytellers for visually impaired children using multi-sensory setups [35],mediating joint attention and enhancing social interaction for children with autism [36]–[38], and increasing engagement in children with attention deficits [39]. Building on these findings, our study utilized the robot's social interactions, content personalization, and demonstration of creative behaviors to support story co-creation activities tailored for neurodivergent children.

Robot-assisted therapy for ASD and ADHD, including storytelling, positively impacted eye contact, social skills, and joint attention [11], [40]. Robots also enhanced verbal participation [41] and engagement in non-verbal children who began to vocalize [42]. However, non-verbal children were at risk of poor outcomes in robot-assisted therapy [43]. To address these needs, we developed a visual interface for non-verbal children, focusing on non-verbal and emotional interactions in story creation.

III. System Design: Creative Stories

A. Genie: Storytelling tool

Genie is a digital mixed-medium creative tool where children can create stories in collaboration with a social robot called Jibo, who aims to foster creative expression through social interaction. Children create stories on a 2-dimensional tablet interface 2. Genie is powered by generative AI technologies aimed to enhance children's creative process and creative product. Genie leverages: (a) speech-to-text capabilities powered by OpenAI's Whisper API, (b) text generation capabilities of OpenAI's GPT-4 for text aids for story completion that is fine-tuned on children's storybook datasets, and (c) image generation and in-painting capabilities of OpenAI's DallE-3 for creating and editing visual imagery. The interface of Genie with corresponding design features is illustrated in figure 4.

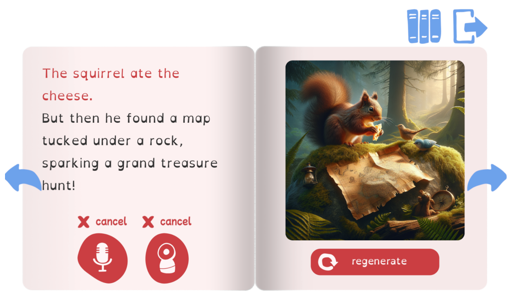

Fig. 1. Interface of Genie: Creative stories tablet application

Genie was iteratively designed and evaluated with children of ages 5-9, teachers, and inclusion staff at the school. We chose this tool to illustrate the design guidelines for creative child-AI interaction because the tool afforded creative expression by children through multiple modalities and generative AI. The story content is prompted to be child appropriate, uses a 2-step child-appropriate check, has a limited dictionary vocabulary for each reading level and uses examples from a set of children's storybooks [44] to create child-friendly content.

B. Storytelling interaction

Storytelling presents an open-ended creative environment that children have a low barrier to enter but wide walls to explore in. It includes collaboration through turn-taking and can afford multiple modalities for creation. It is a process of collaborative emergence [17], where plots can evolve in any direction. Storytelling affords moment-to-moment contingency, where each person's actions depend on and influence the other's, and all participants contribute to the whole of the product. Previous research has explored co-creativity in narrow creative tasks, such as creating titles to abstract images [3]. While these interactions allowed for creative expression within one medium, the creative possibilities had a limited scope. We were interested to study whether design insights from these structured activities can translate to open-ended co-creative environments.

Through "Genie: Stories with Jibo", elementary school students create illustrated stories with Jibo. The story making tool supports verbal and figural creativity through collaborative storytelling, image generation and editing, making drawings, and reading of stories. The interaction is divided into segments integral to collaborative storytelling:

Introduction: Children are introduced to the intent of the task and the robot. Portrait generation: Children create personalized writer profiles by designing AI-generated portraits.

Fig. 2. A child creating a picture story with Jibo using Genie

Beginning: The child and robot collaboratively establish characters, settings, and main topics. Story plot: Together, they build the story plot, addressing conflicts and rising actions. Story climax: The story reaches its peak with the resolution of a conflict. Story ending: Creators conclude the plot with a fitting ending. Publishing and Reading: Stories are published and shared in a digital gallery for peers to view and read.

C. Inclusive Co-creative Child-robot Interaction (ICCRI) Patterns

Drawing from literature on CSTs, creativity support robots, and inclusive child-robot interaction, we designed initial ICCRI patterns to support neurodivergent children's creativity in collaborative tasks with Jibo. We observed participants for four months in a different digital story reading interaction to understand their needs (e.g., lower reading speed) and collaborated with the school's inclusion director to understand every participants' unique needs and prototype interactions *with* them. For instance, we learned that the robot's verbal question-asking may not be suitable for non-verbal children. This iterative co-design process involved developing favorable interactions for participants, gaining expert evaluation with the inclusion director, and re-designing the interactions. In the final suggested ICCRI patterns, Jibo engages the children through verbal and non-verbal cues to foster creative expression throughout the storytelling process. The following ICCRI patterns are presented:

Creativity intent: Interactions in which the robot expresses its intent for a creative action. For instance, upon hearing the child's ideas, and parsing them as relevant stories, the robot says, "Let me try to add to your amazing story and be creative like you!" followed by thinking and drawing animations.

Question asking: The robot asks questions that have children reflect on their creative choices and develop the story narrative. For example, after a student begins a story about a bunny, the robot says, "Oh a [Bunny]! What a great choice. I wonder why you picked a bunny?" The questions are contextual to the child's interactions and the story context.

Positive reinforcement: The robot positively reaffirm students' creative inputs. For instance, when the child creates a drawing, the robot performs a delighted non-verbal response with a happy sound, and says, "That's a beautiful portrait.

I wonder what my portrait would look like? Perhaps like a penguin with one eye!"

Narrative prompts: Narrative prompts advance the story based on the child's story input, the stage of the story, and the story's historical context. For instance, after 30 seconds of inactivity in the beginning, the robot prompts the child with, "Who is the main character of your story?" Upon further inactivity, the robot proactively suggests an idea of how the story can begin.

Divergent thinking: These interactions are intended to help students with divergent thinking (thinking outside the box). When the child asks for the robot's input, the robot would occasionally suggest an idea that diverges from the existing story narrative or introduces a new character through generated images.

Curiosity: The robot shows keen interest in the child's creation and asks questions about the creative product. For example, if the child talks about a giraffe, the robot's utterance is, "A giraffe! I wonder where giraffes live?"

Creativity demonstrations: Learning from previous work demonstrating that children emulate a social robotic peer's expressed creativity, the robot itself expresses creativity in the storytelling interaction through story creation utterances, creating visual imagery, and offering ideas.

Playfulness: The robot assumes a playful demeanor in its animations, verbal interactions and story creations. For instance, while drawing, it plays a rabbit-in-the-hat magic animation on its screen.

Challenges: The robot challenges the child in parts of the story to encourage higher fluency. For instance, during the end of the story, the robot says, "That's an interesting ending. What could be another way to end the story?"

Positive affect: Learning from previous work that demonstrated strong correlations between affect and creativity, we programmed the robot to display positive affect during the interaction to foster creative expression through several non-verbal bodily animations such as excited spinning, delighted dance, happy eyes, and affection when they collaboratively created any artifact.

Feedback: The robot offers feedback for the child's input. For instance, after creating a drawing, the robot would respond with an utterance relevant to the drawing. After a child created a drawing of a frog on a leaf shape, the robot said, "That's a beautiful drawing you made there. It looks like a frog is sitting on a lilypad."

Creating a safe space for failure: The robot modeled a safe space for failure and creative expression by explicitly stating that "I love to recreate and become a better artist" every time a robot idea was not accepted and encouraged multiple tries from the child to get to their desired artifacts.

Multiple modalities of creative expression: Genie supports multiple methods of story creation and robot interaction. Children can speak out their stories, type them out, use graphical visual elements, or prompt the robot to create the story. Supporting multiple modalities of creative expression was designed for students with disabilities; however, we have observed neurotypical students experiment with different styles of creative expression and settle on a preferred one, too.

Personalized interaction: To support students with different reading abilities and cognitive and learning needs, the tool personalized interfaces and interactions to each child. For instance, if a child has a speech impairment, it automatically switches to a visual interface for story creation and avoids open-ended questions, relying instead on non-verbal social and emotional interactions. Five students use non-verbal communication methods. The tool adapts its visual interfaces, reading levels, robot interactions, and story-creation mechanisms to suit each student (Figure 3).

IV. Methods

A. Participants

32 participants (12 f, 20 m) of ages 5–9 were recruited from a school for special education in anonymized country. The students that were recruited were recommended to participate in this study by the school's inclusion director - a special education expert who adapts classroom practices for students with disabilities. The school identified four categories of common barriers to learning that the students faced: (1) Cognition and learning: intellectual disabilities, specific learning disorders, multiple disabilities, and developmental delays, (2) Communication and Interaction: communication disorders, Autism Spectrum Disorder (ASD); (3) Social emotional and mental health: Attention deficit hyperactivity disorder (ADHD), psycho-emotional disorders; and (4) Physical, sensory and medical: sensory impairment, deaf / blind, physical disability, acute medical conditions. Within our participants group, students were formally diagnosed with ASD (n=4), combined type ADHD (n=7), Down's Syndrome (n=1), Hearing impairment (n=1), Cerebral Palsy (n=1), Hemiparesis (n=1), or identified by the school as children needing social, emotional and mental health support (n=6), cognition and learning needs (n=5), or communication and interaction needs (n=2). 5 children in the participant group were non-verbal. All participants and their parents provided informed assent and consent prior to their participation, and the study protocol was approved by the research institute's IRB and the school's inclusion director.

B. Study sessions

We utilized a within-subject multi-session interaction methodology to study the robot's scaffolding patterns' impact on children's creative interactions over multiple encounters. We did not include a control group since the study focuses on measuring students' personal growth with a small group of elementary school children with diverse neurodevelopmental disorders with unique abilities. In this case, it was more insightful for our research questions to study students' own story creation processes and products across subsequent sessions, and using a mixed-methods approach to understand how children with diverse learning needs' creative collaboration with classroom technologies emerges over multiple encounters. Participants interacted with the system for five sessions, each lasting up to 20 minutes: Session 0 (S0) was the baseline condition, creating stories in the robot's absence using all the story creation functionalities without the robot's creativity scaffolding. Session 1 - 3 (S1-3) involved interacting with the social robot Jibo to create picture stories. Post-delayed session 4 (S4), conducted after a 3-month gap from S3, involved story creation in the absence of the robot.

C. Data Collection

1) Video and Audio Data: Video and audio data were collected using a GoPro camera positioned for a bird's-eye view of the child-robot interactions during each session.

2) Interaction logs: Child interactions with Genie—such as recorded stories, image creation and iteration, verbal responses to Jibo, and Jibo's stories—were logged in Firebase[1], a cloud-based data storage service. Jibo interactions—including narrative prompts, creativity intent, feedback, positive reinforcement, creativity demonstrations, curiosity, playfulness, positive affect, question asking, divergent thinking, and challenges—were similarly logged with details of interaction type, time, and duration. The story content, child- and robot-created segments, images, and drawings were also stored in Firebase, along with all iterations of Jibo's stories and whether participants accepted or rejected the robot's contributions or divergent ideas in stories and images.

3) Researcher Observations: Finally, the on-ground researcher conducting the study took notes pertaining to challenges in interaction, robot's support, system errors, and assistive support that the student may require.

D. Analysis Methods

We employ the following methods of evaluating the creative process and product:

1) Creative Process: We study the distributed creativity process between the two creators (the child and the robot) of collaborative emergence inspired from the interaction analysis method by Sawyer and DeZutter [17]. We conducted a thematic analysis of all child interactions that imply creative collaboration. We use a grounded theory approach to conduct a qualitative analysis of interaction patterns. Two coders used one verbal and one non-verbal child's interaction videos to code them with different creative and collaborative interactions that emerged. Both coders then agreed upon common codes, code definitions and underlying themes. Three independent coders used this coding scheme to code 36.7 hours of child-robot interaction video. We used the software ELAN[2] for video coding and its dictionaries to define code presets.

In order to look at the overall effect of the ICCRI patterns on children's creative behaviors, we compare the occurrence of children's creative collaborative process interactions across the sessions. We conducted a one-way Anova test comparing creative collaborative behavior occurrences across the five sessions. We conducted post-doc analysis to compare all session pairs. To understand the effect of specific robot interactions on children's creative collaborative behaviors, we conducted a correlation analysis (Pearson's coefficient) of all Jibo interaction occurrences with child interaction occurrences and correlations between the robot's and the child's divergent thinking behaviors.

2) Creative Product: We used verbal creativity measures from the Torrance Test of Creative Thinking (TTCT) [45]) to measure the creativity of the story. Two independent coders evaluated the story's creativity for (1) Fluency: Total number of story elements expressed verbally by the participant during storytelling, (2) Flexibility: Ideas that fall into different types of categories (i.e., story elements) related to the story plot. These ideas correspond to the total number of characters, actions, scenarios, objects, and affective expressions, and (3) Originality: The level of originality of the ideas during storytelling on a three-point scale (1=low, 2=medium, and 3=high). Coders had a high overall inter-rater reliability (0.84), with the lowest agreement in originality (0.81) and we used an average of the scores reported by the two coders for analysis.

In order to understand how the ICCRI patterns influenced children's creativity over the sessions, we compared children's verbal creativity scores across all 5 sessions and measured the correlation between robot's creativity scaffolding behaviors and children's verbal creativity measures in each session.

3) Access Challenges: Based on researcher notes and analysis of children's interactions, we observed reported access challenges—difficulties the participants encountered while creating stories—and help-seeking behaviors, where participants sought assistance from the researcher, the robot, or their Student Learning Assistant.

V. Results

A. Creative Process

From the thematic coding of children's creative collaborative interactions, the following themes and interaction codes emerged: **Creation:** Story creation; Image creation; Sharing creativity intent; Ideation; Narrative Forming; Divergent thinking. **Iteration:** Story iteration; Image iteration. **Collaboration behaviors:** Adding to robot idea; Reject robot idea; Influenced by robot's idea; Offering new idea; Reading story; Verbal reflection while reading. **Question asking:** Question asking by child; Questions asked to researchers; Question answering with robot. **Feedback:** Act on feedback; Provide feedback; Respond to robot suggestion; Positive reinforcement; Robot provides positive reinforcement. **Miscellaneous:** Curiosity; Satisfaction; Frustration; Challenges; Impatience; Body movements; Emotional attachment.

Most frequent occurrences were of creation interactions, followed by feedback, followed by question asking and iteration (Figure 3). Overall, most variance was observed in feedback behaviors (σ^2=73.9), both across sessions and within participants. Within S1-3, different participants demonstrated vastly different feedback seeking behaviors, that remained consistent with the session. For instance, while one participant exhibited feedback behaviors at an average of 12.7 times across S1-3 (14, 14, 10), another participant exhibited these behaviors

[1]https://firebase.google.com/

[2]The Language Archive (TLA), the Max Planck Institute for Psycholinguistics

TABLE I
CREATIVITY INTERACTIONS ACROSS SESSIONS

Session	Creation	Iteration	Question Asking	Collaboration	Feedback
S0	11.0±5.51	3.06±3.59	0.88±1.5	0.19±0.75	0.0±0.0
S1	10.72±3.84	1.97±2.22	5.16±4.47	1.91±2.1	6.69±4.08
S2	12.05±4.12	3.11±3.25	6.42±6.55	1.42±2.32	12.11±8.43
S3	13.29±4.79	4.14±2.91	4.14±4.3	5.29±4.31	17.29±8.65
S4	13.95±3.95	6.16±5.11	1.32±1.95	2.47±3.55	0.68±1.29

at an average of 2.33 times (3,3,2). Similar differences in creator styles were observed with question asking, curiosity and collaboration. For instance, only four participants engaged in reading peers' stories, but they did so across at least four sessions.

A one-way ANOVA performed to compare the occurrence of children's creative collaborative interactions across sessions confirmed statistically significant differences in iteration behaviors ($F(4,88)=[4.5244]$, $p=0.0023$), question asking behaviors ($F(4,88)=[6.096]$, $p=0.0002$), collaboration behaviors ($F(4,88)=[5.2253]$, $p=0.0008$) and feedback behaviors ($F(4,88)=[26.3233]$, $p=2.297e\text{-}14$) across at least two groups (Table I). Tukey's HSD Test for multiple comparisons found that the mean occurrence of iteration behaviors was significantly different between S1 & S4 ($p=0.001$, 95% C.I.=[-6.985,-1.393]). Participants' iteration behaviors reduced with the introduction of the robot, but eventually increased with multiple encounters with the robot. Tukey's HSD Test for multiple comparisons found that the mean occurrence of question asking behaviors was significantly different between S0 & S1 ($p=0.013$, 95% C.I.=[-7.922,-0.641]), S0 & S2 ($p=0.002$, 95% C.I.=[-9.580,-1.512]), S1 & S4 ($p=0.021$, C.I.=[0.397,7.284]), S2 & S4 ($p=0.004$, C.I.=[1.248,8.963]). Question asking behaviors increased with the introduction of the robot, but the effect did not sustain when the robot was absent in the post-delayed session. The mean occurrence of collaboration behaviors was significantly different between S0 & S3 ($p=0.0001$, C.I.=[-8.338,-1.858]), S1 & S3 ($p=0.018$, C.I.=[-6.363,-0.396]), S2 & S3 ($p=0.009$, C.I.=[-7.026,-0.703]). Participants' question asking behavior increased significantly over subsequent sessions, but the effect did not sustain in the no-robot delayed session. Finally, participants' feedback behaviors significantly increased from S0→S1 ($p=0.009$, C.I.=[-11.025,-2.350]), and from S1→S2 ($p=0.004$, C.I.=[-9.520,-1.315]). However, feedback seeking behaviors significantly reduced in the post-delayed session ($p=0.000$, C.I.=[10.339,22.864]). While it is natural that participants demonstrated no feedback seeking when the robot was absent, participants' feedback seeking seems to have increased with prolonged interaction with the robot.

To understand the effect of ICCRI patterns on children's creative collaboration behaviors, we conducted a correlation analysis between the robot's interaction patterns and children's creative collaborative behaviors. We found significant correlations between the robot's **narrative prompt** with children's creation interactions ($r(74)=0.572$, $p=6.824e\text{-}08$) and their collaboration ($r(74)=0.281$, $p=0.014$), the robot's **creativity intent** with children's creation ($r(74)=0.443$, $p=6.085e\text{-}05$) and iteration ($r(74)=0.553$, $p=2.378e\text{-}07$), the robot's **feedback** with children's creation ($r(74)=0.55$, $p=2.488e\text{-}07$), iteration ($r(74)=0.486$, $p=8.358e\text{-}06$), and collaboration ($r(74)=0.256$, $p=0.025$), the robot's **positive reinforcement** and children's creation ($r(74)=0.320$, $p=0.005$), feedback ($r(74)=0.260$, $p=0.023$), and iteration ($r(74)=0.379$, $p=0.0007$), the robot's **creativity demonstration** and children's creation ($r(74)=0.637$, $p=6.167e\text{-}10$), collaboration ($r(74)=0.459$, $p=2.985e\text{-}05$), and feedback ($r(74)=0.302$, $p=0.008$), the robot's **curiosity** and children's creation ($r(74)=0.592$, $p=1.819e\text{-}08$), collaboration ($r(74)=0.390$, $p=0.0005$), and feedback ($r(74)=0.230$, $p=0.046$), the robot's **question-asking** and children's creation ($r(74)=0.656$, $p=1.255e\text{-}10$) and collaboration ($r(74)=0.310$, $p=0.006$), the robot's **playfulness** and children's iteration ($r(74)=0.509$, $p=2.696e\text{-}06$), and the robot's **positive affect** and children's question asking ($r(74)=0.327$, $p=0.004$) and feedback seeking ($r(74)=0.385$, $p=0.0006$). The robot's **divergent thinking** was significantly correlated with children's iteration ($r(74)=0.459$, $p=2.989e\text{-}05$), but had influence on divergent thinking ($r(74)=0.127$, $p=0.29$). The robot's **challenges** and **creative reflection** prompts were significantly correlated with children's iteration ($r(74)=0.478$, $p=1.25e\text{-}05$).

B. *Creative Product*

All participants in the study, including nonverbal students, created textual and/or visual stories. A total of 106 stories were created across 5 sessions, with 21 stories using the visual interface. Of the 106 stories, 89 consisted of the essential story elements - beginning, character, plot, and end, and 71 also consisted of setting. Incomplete stories were equally distributed across verbal and non-verbal interactions.

A one-way ANOVA was performed to compare the effect of study session on verbal creativity measures (fluency, flexibility, originality, novelty) (Figure II). **Fluency**: A one-way ANOVA revealed that there was a statistically significant difference in fluency of stories between at least two groups ($F(4,101)=4.05$, $p=0.004$). Tukey's HSD Test for multiple comparisons found that the mean value of fluency was significantly different between S0 & S3 ($p=0.001$); S1 & S3 ($p=0.018$); S2 & S3 ($p=0.041$); S3 & S4 ($p=0.022$). This revealed that while multiple sessions had a positive influence on children's fluency (S3), the effect was not sustained when the robot was absent in S4. **Flexibility**: A one-way ANOVA revealed that there was a statistically significant difference in flexibility of the stories between at least two groups ($F(4,101)=8.31$, $p=7.768e\text{-}06$). Tukey's HSD Test for multiple comparisons found that the mean value of flexibility was significantly different between S0 & S1 ($p=0.05$); S0 & S2 ($p=0.004$); S0 & S3 ($p=0.0001$); S1 & S3 ($p=0.004$); S3 & S4 ($p=0.003$). This revealed that while the robot had a significant impact on children's flexibility, and the effect increased with sessions, the effect was not sustained in post-delayed session 4. **Originality**: A one-way ANOVA revealed that there was a statistically significant difference in originality between at least two groups ($F(4,101)=5.411$,

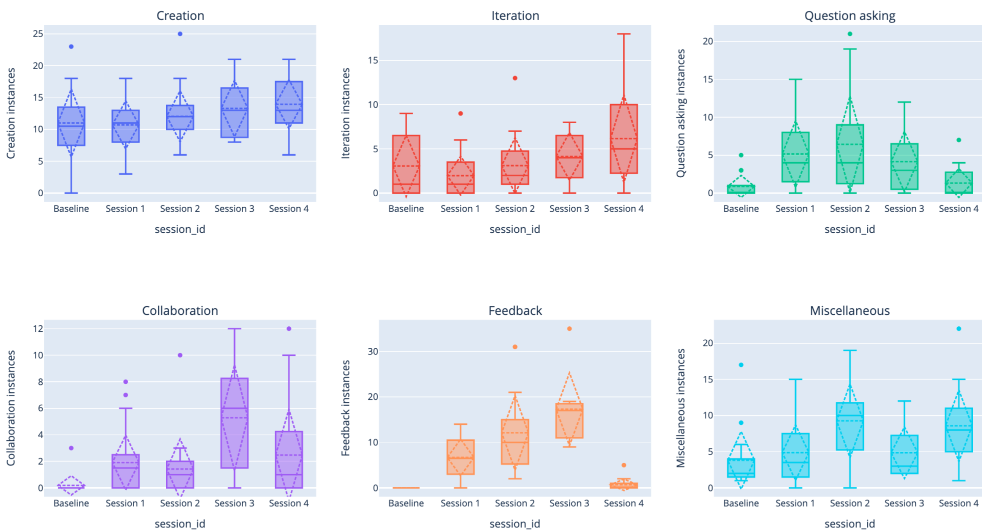

Fig. 3. Children's creative interactions during the sessions

Fig. 4. Heatmap of correlations between ICCRI patterns and children's creative collaborative interactions

TABLE II
CREATIVITY MEASURES ACROSS SESSIONS

Session	Elaboration	Fluency	Flexibility	Originality
S0	152.31±65.99	30.66±12.93	8.24±2.57	1.62±0.62
S1	143.91±85.8	37.38±18.15	10.69±3.38	2.31±0.78
S2	136.05±99.66	38.5±21.43	11.9±4.15	2.3±0.66
S3	86.14±30.06	61.14±17.82	15.86±4.74	2.57±0.53
S4	144.61±81.7	36.33±21.04	10.11±3.32	1.94±0.8

p=0.0005). Tukey's HSD Test for multiple comparisons found that the mean value of originality was significantly different between S0 & S1 (p=0.002); S0 & S2 (p=0.011); S0 & S3 (p=0.016). **Elaboration**: A one-way ANOVA revealed that there was no statistically significant difference in originality between at least two groups (F(4,101)=0.989, p=0.417). This revealed that participants did not show any significant differences in elaboration across group. Since the robot interaction was designed to prompt ending the story in twenty minutes, it was expected that the time constraint may hinder elaboration. In comparing verbal creativity measures across sessions, we observed that participants demonstrated an overall increase in creativity measures from the baseline no-robot session to session 3, with incremental growth in each session. However, the creativity gains were not sustained in the no-robot post session (S4). While participants exhibited higher overall fluency, flexibility and originality in S4 as compared to S0, the difference was not significant (Table II).

A correlation analysis between the robot's ICCRI patterns in the robot sessions (S1-3) and children's verbal creativity revealed statistically significant positive correlations between the following: the robot's **creativity intent** and the children's elaboration (r(108)=0.374, p=0.004), flexibility (r(108)=0.396, p=0.002), and fluency (r(108)=0.351, p=0.006); the robot's **positive affect** and the children's elaboration (r(108)=0.337, p=0.009), fluency (r(108)=0.316, p=0.015), flexibility (r(108)=0.354, p=0.006), and originality (r(108)=0.270, p=0.039); the robot's **positive reinforcement** and the children's elaboration (r(108)=0.336, p=0.009), fluency (r(108)=0.262, p=0.0452), and flexibility (r(108)=0.345, p=0.008); the robot's **feedback** and children's flexibility (r(108)=0.298, p=0.022) and fluency (r(108)=0.263, p=0.044); robot's **divergent thinking** and elaboration (r(108)=0.516, p=2.92e-05); and the robot's **playfulness** and children's flexibility (r(108)=0.310, p=0.017). There were also statistically significant negative correlations between the robot's **curiosity** and children's originality (r(108)=-0.292, p=0.025), and the robot's **creativity demonstration** and children's originality (r(108)=-0.322, p=0.013). This suggested that ICCRI especially benefited children's fluency, flexibility and elaboration; however, the robot exhibiting curiosity and creative ideas hampered children's originality.

The robot (or system in S0,4) also expressed divergent thinking through introducing novel elements in the story or image with a 1:4 probability. Participants were less likely to reject divergent ideas in robot conditions (S1=11%; S2=18%, S3=16.6% rejection) as compared to in non-robot conditions (S0=24.6%, S4=37.03% rejection). Participants collaborated with the robot to create images for their picture stories, often iterating over the image and recreating until they reached a desired image. The images created per session tended to increase from S0→S1→S2→S3→S4. A one-way ANOVA test revealed that there was a statistical difference between the images iterated over in the five sessions ($F(4,94)=5.842$, $p=0.0003$). Tukey's HSD Test for multiple comparisons found that the mean value of image iterations were significantly different in S0 ($\bar{x}=5.13\pm1.79$) & S2 ($\bar{x}=8.11\pm4.36$) ($r=-2.98$, $p=0.006$) and S0 ($\bar{x}=5.13\pm1.79$) & S4 ($\bar{x}=8.56\pm3.29$) ($r=-3.424$, $p=0.001$). This indicates that the robot's presence had an overall positive impact on children's image iteration, and this effect stayed in S4.

Finally, a thematic analysis of access challenges noted in video annotations and researcher notes yielded the following themes: (1) technical challenges (e.g. voice recognition issues), (2) creation hindrance (e.g. inability to create drawings), or (3) ideation roadblocks (e.g. child is struggling to proceed). The challenges reported decrease from S0(6.41 ± 1.36)→S1(4.22 ± 1.6)→S2(3.89 ± 0.45)→S3, but increase in S4(4.85 ± 1.8). While the challenges in S4 are less than S0, non-verbal students especially struggled to create in the absence of the robot.

VI. Discussion

In this work, we designed Inclusive Co-creative Child-Robot Interaction patterns and validated them in a user study with 32 neurodivergent students. To explore the impact of ICCRI patterns, we supplemented quantitative analysis, such as the evolution of verbal creativity across multiple encounters, with an in-depth qualitative lens, such as occurrences of the emergent child-robot creative collaborations. Confirming hypothesis **H1.**, we observed that the system supported story creation for children with diverse needs. Non-verbal students successfully used the visual Genie interface to create stories. Students were able to communicate with the robot in language complexities personalized to them. Confirming **H2.1.**, we observed that children in the first robot encounter (S1) exhibited higher verbal creativity than the baseline no-robot session. However, we could only partially confirm **H2.2.** where with repeated interactions with the robot, children exhibited higher verbal creativity (fluency, flexibility and originality) in their stories, but this effect was not sustained in the post-delayed S4 without the robot. Creativity effects that multiple encounters with the robot afforded children was not sustained in a post-delayed no-robot condition. This may indicate that while the system is beneficial for creativity, three intervention sessions are too few to lead to long-term creativity effects, and more number and frequency of sessions may be beneficial. While creativity dropped from S3 to S4, participants creativity (in the process and the product) in S4 is significantly higher than the baseline S0. We partially confirmed **H3**. where the robot's creativity scaffolding such as expressing creativity intent, asking questions or providing positive reinforcement were correlated with children's creative collaborative behaviors such as iteration and question asking. However, ICCRI patterns divergent thinking and question asking were not correlated with collaboration and feedback seeking behaviors.

We observed significant variation in the types of creative interactions during the storytelling task. One student consistently sought feedback from the robot, while another rejected all feedback. Most students co-created images with the robot, but five chose to avoid this feature. This aligns with previous research on the diverse creation styles of neurodivergent children. A key strength of our system was its ability to accommodate these differences by offering multiple open-ended pathways for story creation. While we propose generalizable ICCRI patterns, it is crucial that CSTs are flexible to adapt to individual needs. Conducting experiments with personalized technologies with a unique population also poses challenges. As high variances in our data show, establishing a balanced control and experimental group is immensely difficult with a small group of neurodivergent learners because of the large difference in their skill levels. Providing equal opportunity for intervention for all participants was a goal that the researchers upheld aligned with the school and parents' wishes. In an ideal case, one could design a longer study where the students in the control group become the experimental group in the following term to fulfill this goal.

Although CSTs are becoming more common, they are often not designed with disabilities in mind. In this work, we leverage social robots' ability to provide scaffolding in collaborative creative tasks to support creativity in children with neurodevelopmental disorders. In HRI, we have a unique opportunity to combine robots' social skills with AI's creative advancements to design inclusive interactions. However, sustaining creativity gains beyond the robot's presence remains a challenge. In our 5-session study, we found that the creativity improvements were not maintained in a delayed post-session, particularly for children who relied heavily on the robot's scaffolding. More frequent and longer studies are needed to understand the long-term impact of these interventions.

VII. Conclusion

In this work, we present Inclusive Co-creative Child-Robot Interaction (ICCRI) patterns for supporting neurodivergent children's creativity through a collaborative storytelling application with the social robot Jibo. Our findings demonstrate that inclusive design principles and personalized creativity scaffolding can reduce barriers to creativity for children with neurodevelopmental disorders. Over multiple sessions, children exhibited increased verbal creativity, enhanced collaboration, and emergence of different creator styles. These results are valuable for designing long-term, inclusive child-robot interactions fostering creativity, while also highlighting the need for adaptive interactions that sustain creative engagement beyond robot-assisted sessions. One limitation of this work is that due to a small sample size we did not separately analyze children's creative product or process for different neurodevelopmental disorders, age, verbal, or language abilities. Future work will involve more frequent child-robot interactions to study a real-world sustained impact of the ICCRI.

REFERENCES

[1] J. C. Kaufman and R. J. Sternberg, *The Cambridge handbook of creativity*. Cambridge University Press, 2010.

[2] P. Alves-Oliveira, P. Arriaga, C. Xavier, G. Hoffman, and A. Paiva, "Creativity landscapes: Systematic review spanning 70 years of creativity interventions for children," *The Journal of Creative Behavior*, vol. 56, no. 1, pp. 16–40, 2022.

[3] S. Ali, N. Devasia, H. W. Park, and C. Breazeal, "Social robots as creativity eliciting agents," *Frontiers in Robotics and AI*, vol. 8, p. 673730, 2021.

[4] P. Alves-Oliveira, P. Arriaga, A. Paiva, and G. Hoffman, "Yolo, a robot for creativity: A co-design study with children," in *Proceedings of the 2017 Conference on Interaction Design and Children*, 2017, pp. 423–429.

[5] M. E. Ligthart, M. A. Neerincx, and K. V. Hindriks, "Design patterns for an interactive storytelling robot to support children's engagement and agency," in *Proceedings of the 2020 ACM/IEEE international conference on human-robot interaction*, 2020, pp. 409–418.

[6] S. Ali, T. Moroso, and C. Breazeal, "Can children learn creativity from a social robot?" in *Proceedings of the 2019 Conference on Creativity and Cognition*, 2019, pp. 359–368.

[7] S. Ali, H. W. Park, and C. Breazeal, "A social robot's influence on children's figural creativity during gameplay," *International Journal of Child-Computer Interaction*, vol. 28, p. 100234, 2021.

[8] S. Ali, N. E. Devasia, and C. Breazeal, "Escape! bot: Social robots as creative problem-solving partners," in *Proceedings of the 14th Conference on Creativity and Cognition*, 2022, pp. 275–283.

[9] M. Hoggenmueller, M. L. Lupetti, W. Van Der Maden, and K. Grace, "Creative ai for hri design explorations," in *Companion of the 2023 ACM/IEEE International Conference on Human-Robot Interaction*, 2023, pp. 40–50.

[10] P. H. Kahn, T. Kanda, H. Ishiguro, B. T. Gill, S. Shen, J. H. Ruckert, and H. E. Gary, "Human creativity can be facilitated through interacting with a social robot," in *2016 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 2016, pp. 173–180.

[11] A. Sandygulova, Z. Zhexenova, B. Tleubayev, A. Nurakhmetova, D. Zhumabekova, I. Assylgali, Y. Rzagaliyev, and A. Zhakenova, "Interaction design and methodology of robot-assisted therapy for children with severe asd and adhd," *Paladyn, Journal of Behavioral Robotics*, vol. 10, no. 1, pp. 330–345, 2019. [Online]. Available: https://doi.org/10.1515/pjbr-2019-0027

[12] L. A. Dickstein-Fischer, D. E. Crone-Todd, I. M. Chapman, A. T. Fathima, and G. S. Fischer, "Socially assistive robots: current status and future prospects for autism interventions," *Innovation and Entrepreneurship in Health*, pp. 15–25, 2018.

[13] B. Scassellati, H. Admoni, and M. Matarić, "Robots for use in autism research," *Annual review of biomedical engineering*, vol. 14, no. 1, pp. 275–294, 2012.

[14] P. Meusburger *et al.*, "Milieus of creativity: The role of places, environments, and spatial contexts," *Milieus of creativity: An interdisciplinary approach to spatiality of creativity*, vol. 2, pp. 97–153, 2009.

[15] J. P. Guilford, "Creativity: Yesterday, today and tomorrow," *The Journal of Creative Behavior*, vol. 1, no. 1, pp. 3–14, 1967.

[16] R. K. Sawyer and D. Henriksen, *Explaining creativity: The science of human innovation*. Oxford university press, 2024.

[17] R. K. Sawyer and S. DeZutter, "Distributed creativity: How collective creations emerge from collaboration." *Psychology of aesthetics, creativity, and the arts*, vol. 3, no. 2, p. 81, 2009.

[18] T. M. Amabile and N. D. Gryskiewicz, "The creative environment scales: Work environment inventory," *Creativity research journal*, vol. 2, no. 4, pp. 231–253, 1989.

[19] L. A. Witt and M. N. Beorkrem, "Climate for creative productivity as a predictor of research usefulness and organizational effectiveness in an r&d organization," *Creativity Research Journal*, vol. 2, no. 1-2, pp. 30–40, 1989.

[20] M. Resnick, "All i really need to know (about creative thinking) i learned (by studying how children learn) in kindergarten," in *Proceedings of the 6th ACM SIGCHI conference on Creativity & cognition*, 2007, pp. 1–6.

[21] G. Ellis and J. Brewster, "The storytelling handbook: A guide for primary teachers of english," *(No Title)*, 1991.

[22] S. Engels, "The stories children tell," 1999.

[23] W. Labov, *Language in the inner city: Studies in the Black English vernacular*. University of Pennsylvania Press, 1972, no. 3.

[24] A. McCabe, "Developmental and cross-cultural aspects of children's narration," in *Narrative development*. Routledge, 2012, pp. 137–174.

[25] L. Polanyi, "What stories can tell us about their teller's world," *Poetics Today*, vol. 2, no. 2, pp. 97–112, 1981.

[26] N. K. Aiex, *Storytelling: Its wide-ranging impact in the classroom*. ERIC Clearinghouse, 1988.

[27] A. Nicolopoulou, "Narrative development in social context1," in *Social interaction, social context, and language*. Psychology Press, 2014, pp. 369–390.

[28] A. Kasirer, E. Adi-Japha, and N. Mashal, "Verbal and figural creativity in children with autism spectrum disorder and typical development," *Frontiers in psychology*, vol. 11, p. 559238, 2020.

[29] S. H. Yoon, A. Verma, K. Peppler, and K. Ramani, "Handimate: exploring a modular robotics kit for animating crafted toys," in *Proceedings of the 14th International Conference on Interaction Design and Children*, 2015, pp. 11–20.

[30] M. Ott and F. Pozzi, "Digital games as creativity enablers for children," *Behaviour & Information Technology*, vol. 31, no. 10, pp. 1011–1019, 2012.

[31] S. Jacoby and L. Buechley, "Drawing the electric: storytelling with conductive ink," in *Proceedings of the 12th International Conference on Interaction Design and Children*, 2013, pp. 265–268.

[32] M. Elgarf, G. Skantze, and C. Peters, "Once upon a story: Can a creative storyteller robot stimulate creativity in children?" in *Proceedings of the 21st ACM International Conference on Intelligent Virtual Agents*, 2021, pp. 60–67.

[33] M. Elgarf, N. Calvo-Barajas, P. Alves-Oliveira, G. Perugia, G. Castellano, C. Peters, and A. Paiva, ""“and then what happens?” promoting children's verbal creativity using a robot," in *2022 17th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 2022, pp. 71–79.

[34] P. Alves-Oliveira, P. Arriaga, M. A. Cronin, and A. Paiva, "Creativity encounters between children and robots," in *Proceedings of the 2020 ACM/IEEE international conference on human-robot interaction*, 2020, pp. 379–388.

[35] C. Antunes, I. Neto, F. Correia, A. Paiva, and H. Nicolau, "Inclusive'r'stories: An inclusive storytelling activity with an emotional robot," in *2022 17th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, 2022, pp. 90–100.

[36] B. Robins, K. Dautenhahn, and P. Dickerson, "From isolation to communication: A case study evaluation of robot assisted play for children with autism with a minimally expressive humanoid robot," in *2009 Second International Conferences on Advances in Computer-Human Interactions*, 2009, pp. 205–211.

[37] B. Robins, K. Dautenhahn, R. T. Boekhorst, and A. Billard, "Robotic assistants in therapy and education of children with autism: can a small humanoid robot help encourage social interaction skills?" *Universal Access in the Information Society*, vol. 4, no. 2, pp. 105–120, 2005. [Online]. Available: https://doi.org/10.1007/s10209-005-0116-3

[38] B. Robins, P. Dickerson, P. Stribling, and K. Dautenhahn, "Robot-mediated joint attention in children with autism: A case study in robot-human interaction," *Interaction Studies*, vol. 5, no. 2, pp. 161–198, 2004. [Online]. Available: https://www.jbe-platform.com/content/journals/10.1075/is.5.2.02rob

[39] F. Amato, M. Di Gregorio, C. Monaco, M. Sebillo, G. Tortora, and G. Vitiello, "Socially assistive robotics combined with artificial intelligence for adhd," in *2021 IEEE 18th Annual Consumer Communications and Networking Conference (CCNC)*, 2021, pp. 1–6.

[40] B. Scassellati, L. Boccanfuso, C.-M. Huang, M. Mademtzi, M. Qin, N. Salomons, P. Ventola, and F. Shic, "Improving social skills in children with asd using a long-term, in-home social robot," *Science Robotics*, vol. 3, no. 21, p. eaat7544, 2018. [Online]. Available: https://www.science.org/doi/abs/10.1126/scirobotics.aat7544

[41] D. Silvera-Tawil, D. Bradford, and C. Roberts-Yates, "Talk to me: The role of human-robot interaction in improving verbal communication skills in students with autism or intellectual disability," in *2018 27th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, 2018, pp. 1–6.

[42] N. Rakhymbayeva, N. Seitkazina, D. Turabayev, A. Pak, and A. Sandygulova, "A long-term study of robot-assisted therapy for children with severe autism and adhd." New York, NY, USA: Association for Computing Machinery, 2020. [Online]. Available: https://doi.org/10.1145/3371382.3378356

[43] A. Zhanatkyzy, Z. Telisheva, A. Amirova, N. Rakhymbayeva, and A. Sandygulova, “Multi-purposeful activities for robot-assisted autism therapy: What works best for children’s social outcomes?” in *Proceedings of the 2023 ACM/IEEE international conference on human-robot interaction*, 2023, pp. 34–43.

[44] N. Mostafazadeh, N. Chambers, X. He, D. Parikh, D. Batra, L. Vanderwende, P. Kohli, and J. Allen, “A corpus and evaluation framework for deeper understanding of commonsense stories,” *arXiv preprint arXiv:1604.01696*, 2016.

[45] E. P. Torrance, “Torrance tests of creative thinking,” *Educational and psychological measurement*, 1966.