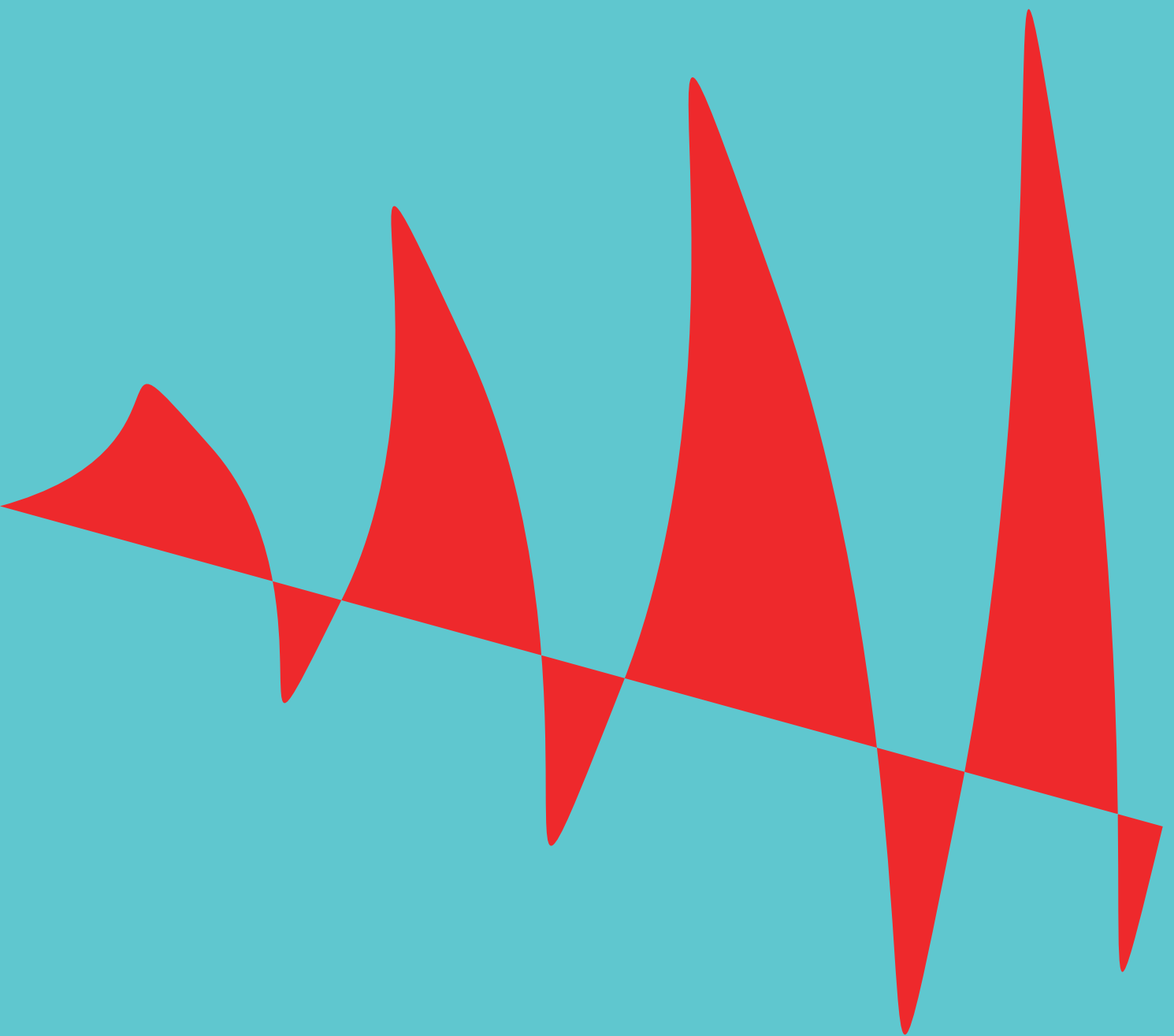


Drawing with Le Magique: Embodied AI for Facilitating Artistic Expression in Children



Designing an age-adaptive embodied AI system which can adapt to the child from 2 years to 11 years and act as a creative collaborator.

Master Thesis

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Finally, to my friends and family, whose constant support and optimism gave me the courage to follow my instincts and make this project a success.

AI Use Statement

AI tools were used at several stages of this project. In writing the report, AI was used to refine and edit the text for cohesion and grammar. AI was used to generate some images from initial sketches, to communicate ideas more clearly. It was also used to help generate graphs and flowcharts through Python. Finally, as the core aim of the project was to build a co-creative workflow with generative AI, an AI coding assistant was used to help develop the prototype itself (so-called “vibe coding”).

Throughout, the intellectual direction, design decisions, analysis, and conclusions are my own; AI served as a support tool rather than a source of the work's content.

Abstract

Creativity is central to how children explore and make sense of the world, yet the divergent, playful thinking that underpins it is often marginalised by education systems that favour concrete reasoning, and further eroded by a digital landscape of passive consumption and shortening attention spans. Compounding this, most creative technologies and creative social robots are designed for a narrow age range and short-term use, and cannot evolve alongside a growing child. This thesis asks how an embodied AI system might facilitate children's artistic expression across childhood, and how its behaviour must adapt across three developmental brackets – 2–4, 5–7, and 8–11 years.

The project followed an exploratory design approach with a concentration on Human Centred Design & Participatory Design. A literature review, expert interviews with teachers, and participatory co-design workshops with children first established how creative and collaborative behaviours differ by age, and translated these into design requirements for an age-adaptive AI system that co-creates with the child. These requirements were realised as a proof-of-concept, Le Magique Drawing: an embodied AI system that reads and analyses a child's drawing with a vision-language model and projects age-calibrated suggestions from three distinct personalities (additions, realism, and imagination) directly onto the child's paper, sustaining a continuous "back-and-forth" drawing loop while keeping the child the author of the work.

The prototype was evaluated with children across the three age groups in Wizard-of-Oz sessions. It engaged them strongly and supported their creativity within the act of drawing: they explored beyond the familiar, reworked the system's suggestions into ideas of their own, and remained the authors of their work. Tellingly, the developmental gradient anticipated in the workshops reappeared in testing, and in places the co-creation visibly matured the drawings themselves. Its value did, however, prove conditional on how well the system adapted to the individual child – a finding that reframes the central design challenge from generating good suggestions to delivering them with personalization, to each child's intent, and pace. This work contributes an evaluated proof-of-concept and a set of design guidelines for age-adaptive, embodied AI that supports children's artistic expression, and charts the path to a fully adaptive, embodied next iteration.

“Every child is an artist.

*The problem is how to remain
an artist once he grows up.”*

- Pablo Picasso

1. Introduction

1.1 Background & Context

1.2 Research Questions

1.3 Project Objectives

1.4 Methodology

1.1 Background & Context

Contemporary children's toys increasingly incorporate digital intelligence, interactivity, and robotic behaviour. Within this landscape, modular robotic toy kits such as LEGO Robotics have demonstrated the potential of construction-based play to introduce children to technology through hands-on interaction. In parallel, interactive social robots (expressive companions to collaborative technological tools) have explored how movement, responsiveness, and personality can engage children in playful scenarios (Rudenko et al., 2024). Prior academic and design work, including projects such as ModuDK (MODU – Life-Size Building Toys for Active Play, n.d.), Roball (Michaud & Caron, 2002), and earlier thesis explorations of interactive toy robots (Tang, 2020), illustrates a growing interest in both modularity and social interaction as key qualities in children's toys.

Despite these developments, the current state of the art reveals a significant limitation: most robotic companions and modular kits are designed for narrow age ranges and short-term engagement (Chen et al., 2025). As children grow, their cognitive, emotional, and creative needs change rapidly, often rendering these toys obsolete within a short period. The majority of existing social robots and building systems lack the adaptive capacity to evolve alongside children from early childhood into later developmental stages (Malnatsky et al., 2025). In particular, there is a notable gap in the design of social robots that children can continuously collaborate with, rather than just passively consume, allowing for deep, creative, and age-appropriate engagement over extended periods of time (Gao et al., 2020).

Current educational robot systems largely frame play through an instructional lens, prioritizing structured learning outcomes such as programming skills, logical reasoning, or STEM knowledge acquisition. While these objectives are valuable, they often come at the expense of open-ended play and curiosity-driven exploration (Yazgin, 2021). Many social robotic toys require children to follow rigid interaction scripts before meaningful engagement can occur. However, children do not always seek instruction when playing; often, they are more motivated by companions that immediately capture their interest and invite freeform experimentation. This highlights an unmet need for social robots that prioritize intuitive interaction, creative freedom, and playful discovery over explicit educational outcomes (Anik et al., 2024).

This project is grounded in the belief that creativity is central to children's development. Here, creativity is understood not as exceptional artistic talent but in its everyday, developmental sense – the capacity to produce something both original and personally meaningful (Runco & Jaeger, 2012; Kaufman & Beghetto, 2009). For a young child, this lies less in the polish of a finished product than in the imaginative, combinatorial reworking of experience into something new, an act Vygotsky (2004) considered creative whether its outcome is a physical object or an idea that exists only in the child's own mind. This perspective frames play not as a means to an external learning goal, but as a fundamental mode through which children explore, imagine, and make sense of the world. Designing social robotic systems that preserve and support this child-like curiosity requires a shift away from purely instructional paradigms towards responsive systems that encourage imagination, improvisation, and self-directed engagement.

An essential dimension of this challenge lies in the social nature of play. Social interaction plays a critical role in how children engage with technology over time. Consequently, this project draws on research from the field of Child-Robot Interaction (CRI) to understand how robots can meaningfully participate in and facilitate children's creative play. By analyzing existing literature, interviewing teachers as experts, conducting small-scale exploratory workshops with children, and creating a proof-of-concept prototype, the project aims to create a social robotic system that supports long-term, socially engaging, and creative collaborative tasks.

The overarching goal of this graduation project is to design an age-adaptive social robotic system that facilitates creativity and can accompany a child from early childhood (approximately 3–4 years) through later childhood (up to 12 years). The proposed system is envisioned as a dynamic social companion that evolves its interaction modalities, scaffolding techniques, and creative prompts according to the child's developing interests and cognitive abilities. Rather than offering a single fixed set of interactions, the system aims to adapt across developmental stages by enabling modes of play—ranging from sensory and exploratory mediation for toddlers to complex, collaborative co-creation for older children. By situating this project at the intersection of social robotics, creative play, and child-robot interaction, the following project examines existing work in these domains to identify gaps, limitations, and opportunities that inform the design of an age-adaptive, creativity-focused social robotic system.

1.2 Research Questions

Part-1: Understanding the Users

Q) How do cognitive, social, and collaborative behaviors during creative play develop across different childhood age groups?

1. What types of creative activities, materials, and sensory experiences best engage children at varying developmental stages?
2. How do dynamics in creative collaborations evolve with different age groups?

Part-2: Designing the Intervention

Q) What are the design requirements for an age-adaptive social robotic system aimed at facilitating long-term creative engagement in children?

1. What distinct social role should the robot adopt to support creative collaboration with different age groups?
2. How should the robot's interaction behaviors and physical affordances dynamically adapt to match a child's evolving cognitive needs?
3. What specific co-creative activities can the robot and child undertake to ensure a "back-and-forth" interaction loop?
4. What non-verbal cues and social behaviors must the robot exhibit to clearly convey its intentions and adapt to different age-groups?

1.3 Project Objectives

1. Identify key cognitive, social, and collaborative behaviors across different childhood age groups to deeply understand their evolving creative needs.
2. Develop a Child-Robot Collaboration (CRC) workflow that defines a "back-and-forth" co-creation process between the user and the system.
3. Establish a comprehensive design framework for an age-adaptive social robotic system, translating behavioral insights into specific hardware and software requirements.
4. Design and build a proof-of-concept prototype of the age-adaptive social robot that embodies the developed framework.
5. Conduct small-scale user testing to evaluate the prototype's effective social-interaction, engagement levels, and ability to dynamically adapt to different age groups.
6. Using testing feedback and insights to deliver a refined, final design proposal for the co-creative robotic system.

1.4 Methodology

Literature Review (Snyder, 2019)

A literature review forms the foundation of the project, establishing its theoretical grounding and situating the work within existing research. It surveys child development theory, play and creativity, child–robot interaction, the measurement of creativity, and the current state of the art in creative and social robots. The review serves both to build an informed understanding of the problem space and to identify the gaps and opportunities that motivate the project's direction and research questions.

Expert Interviews (Bogner et al., 2009)

Expert interviews are conducted as the first stage of primary research, complementing the literature with grounded, practice-based insight. Semi-structured interviews are held with experienced educators across the three target age groups, who observe children's creative behaviour daily and already perform some facilitating role the robot is intended to support. The interviews translate the general principles drawn from the literature into concrete, age-specific observations about creative engagement, collaboration, and the reception of social robots.

Thematic Analysis (Braun & Clarke, 2006)

Thematic analysis is the qualitative method used to interpret the interview data. Following an inductive, bottom-up approach, the responses are coded and the codes grouped into recurring themes, allowing patterns of meaning to emerge from the educators' own accounts rather than being imposed in advance. The resulting themes are then carried forward to inform the design requirements for the robot.

Co-Design/Creative Workshops (Sanders & Stappers, 2008)

Co-design and creative workshops involve children directly as partners in the design process. Conducted in a familiar school setting with participants across the three age brackets, the workshops use hands-on creative activities – such as collaborative construction and drawing – to surface children's social behaviours, collaborative dynamics, and expectations of a robot companion. As the end users, the children act as co-researchers, providing design insights that an adult designer could not anticipate alone.

Research-through-Design (RtD) (Zimmerman et al., 2007)

The second phase of the project adopts a Research-through-Design methodology, in which knowledge is generated through the act of designing and building rather than studied in the abstract. Here, the design and iterative refinement of a working proof-of-concept becomes the primary mode of inquiry: each prototype tests assumptions, surfaces new questions, and produces insight that feeds back into the design. The following methods structure this phase. Especially, focused on prototyping & iteration.

Prototyping & Iteration (Stappers & Giaccardi, 2017)

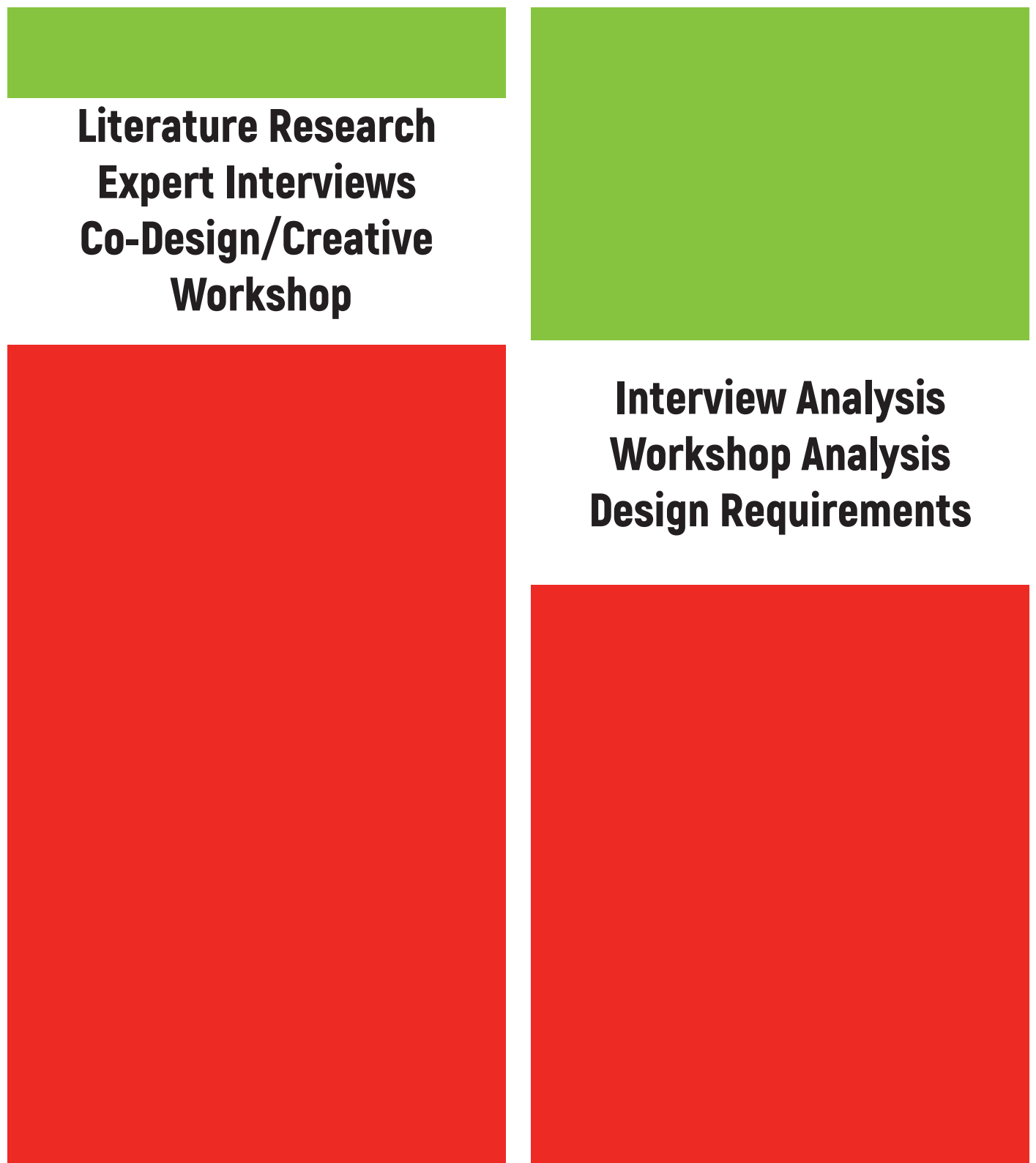
Within the Research-through-Design phase, prototyping is the central activity through which ideas are made tangible, tested, and refined. The design requirements are first translated into a working proof-of-concept so that abstract intentions can be experienced rather than only imagined. This prototype is then placed in front of children in structured sessions (experimentation), where its effect on their creative output, engagement, and social interaction is observed and assessed against the creativity measures established earlier. The resulting insights feed back into successive rounds of refinement (iteration), each cycle of building, testing, and revising improving the system's behaviour, suggestions, and expressiveness. Finally, the refined prototype is validated against the project's goals and design requirements – tested with children and evaluated through their creative artefacts and interactions, supported where appropriate by educators' perspectives – to confirm whether the design meaningfully facilitates artistic expression & creativity, and adapts across age groups. Together, prototyping, experimentation, iteration, and validation form a single, looping make–test–refine cycle that is the engine of the Research-through-Design process.

1.4.1 Phase 1

Research & Contextualizing

Week 1 - Week 5

Week 6 - Week 12



Literature Research
Expert Interviews
Co-Design/Creative
Workshop

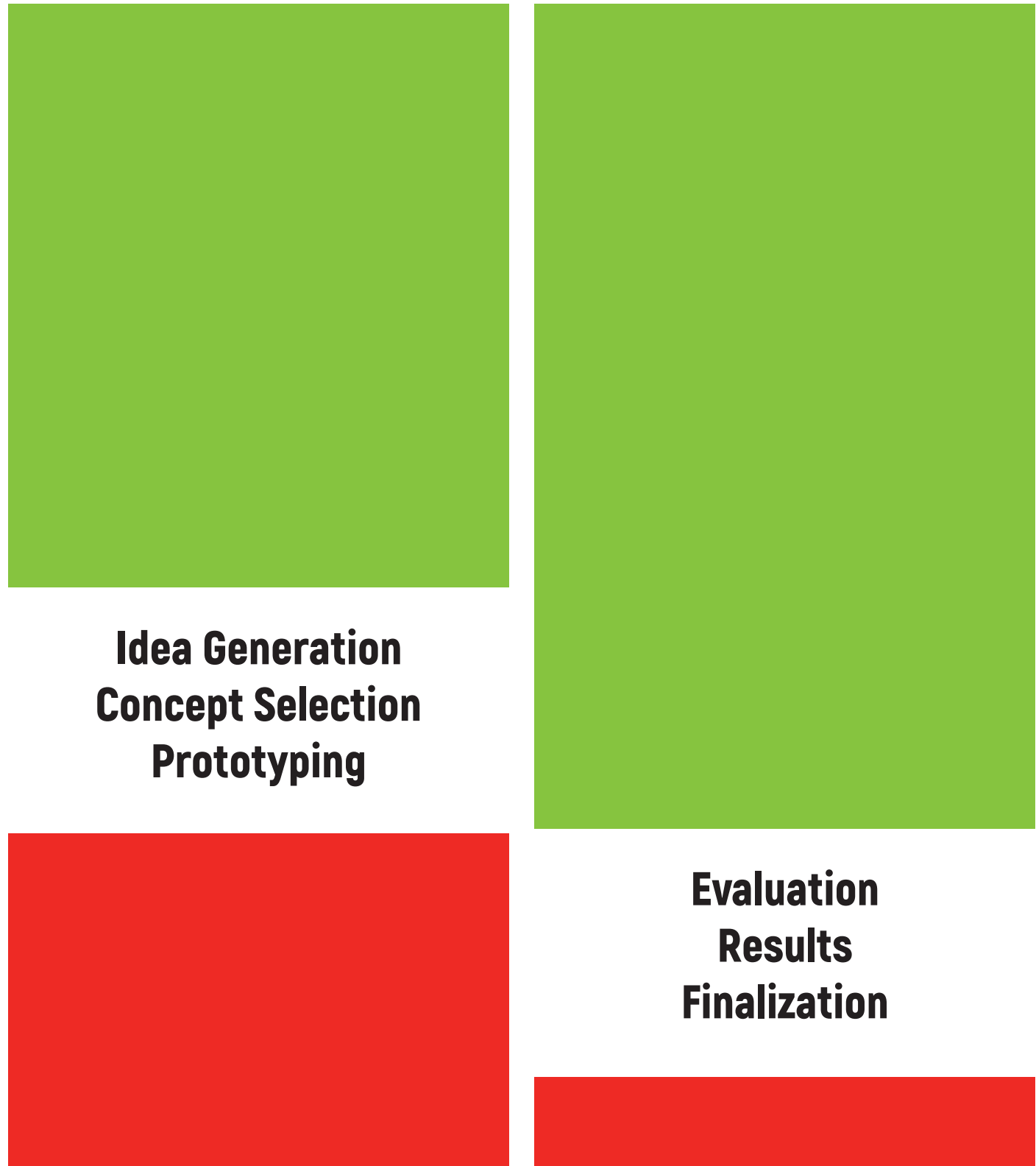
Interview Analysis
Workshop Analysis
Design Requirements

1.4.2 Phase 2

Development & Testing

Week 10 - Week 16

Week 16 - Week 20



Idea Generation
Concept Selection
Prototyping

Evaluation
Results
Finalization

2. Literature Review

2.1 Child Cognitive Development

2.2 Play & Creativity

2.3 Child Robot Interaction

2.4 Evaluation of Creativity

2.5 State of Art (Creative Social Robot Systems)

2.6 Participatory Design with Kids

2.7 Key Findings

2.1 Child Cognitive Development

Within the domain of child development research, various theoretical lenses exist (Keenan & Evans, 2016). These theories explore how children's cognitive and emotional needs evolve with age and debate the conditions necessary for rearing, instruction, recreation, and resource provision as children approach adolescence. Within the context of this project, the following four theories have been analyzed to establish a framework for design requirements across different developmental stages: Erikson's Psychosocial Theory, Piaget's Theory of Cognitive Development, Vygotsky's Theory, and Montessori's Educational Philosophy.

2.1.1 Erikson's Psychosocial Theory (Keenan & Evans 2016) (Erikson 1950)

This theory posits that three interconnected systems drive cognitive development in children. Primarily, the Somatic System comprises the biological components, focusing on physical growth and physiological maturation. Secondly, the Ego System governs cognitive functions such as reasoning and reflection; it represents the developing sense of self that evolves through novel experiences and social interactions. Thirdly, the Social System involves integration into the broader community, representing the cultural and environmental contexts of development.

Based on these systems, Erikson identified eight developmental stages, each characterized by a fundamental psychosocial conflict. For this project, the focus is restricted to three specific stages:

Early Childhood (1–3 years): The primary conflict is Autonomy vs. Shame and Doubt. Children seek personal control; insecurities may arise if they are coerced into activities or denied independent choice.

Play Age (3–6 years): The central conflict is Initiative vs. Guilt. This stage involves a desire to master the environment through exploration; a perceived failure to achieve this mastery can result in a sense of guilt.

School Age (7–11 years): The conflict is Industry vs. Inferiority. Children exhibit a keen desire to master intellectual and social challenges; failure to meet these standards may foster a lasting sense of inferiority.

2.1.2 Piaget's Theory of Cognitive Development (Keenan & Evans 2016) (Piaget 1950)

Jean Piaget contended that the human mind functions as an adaptive mechanism, ensuring that knowledge provides an accurate "fit" to the external world. His theory posits that children progress through four distinct stages of development: Sensorimotor (0–2 years), Preoperational (2–7 years), Concrete Operational (7–11 years), and Formal Operational (12+ years). This framework is predicated on the belief that internal dynamics within the individual drive behavior. Consequently, children continuously revise their understanding to better align with reality as they incorporate novel experiences and findings into their existing cognitive structures.

To elaborate, Piaget proposed that children actively construct their own reality through the manipulation and exploration of their environment, developing mental structures termed schemes. The fundamental mechanism driving this development is the adaptation and organization of information; thus, the primary challenge in cognitive development is the establishment of equilibrium between the child's internal perceptions and the external world.

The characteristics of the first three stages are defined as follows:

Sensorimotor Stage: Children conceptualize the world primarily through physical actions and sensory perceptions.

Preoperational Stage: Children develop the capacity for symbolic representation and mental imagery.

Concrete Operational Stage: Children exhibit increasingly logical and structured thinking patterns.

During the preoperational stage (ages 2–7), Piaget introduced the concept of egocentrism, wherein a child perceives the world solely from their own perspective and lacks the cognitive capacity to understand the viewpoints of others. This period also marks the emergence of pretend play around age two. In these scenarios, children utilize physical objects to enact imaginary roles that may exceed their actual capabilities, a process vital for forging social bonds with the external world. Furthermore, this stage is characterized by animistic thinking, in which children attribute lifelike qualities and intentions to inanimate objects.

2.1.3 Vygotsky's Theory of Cognitive Development (Keenan & Evans 2016) (Vygotsky 1978)

Vygotsky asserted that a child's social environment is paramount, directly influencing their cognitive development. The manner in which children acquire knowledge profoundly contextualizes their growth. Central to this theory is the critical role of language, which progresses through three distinct stages: social speech, private speech, and inner speech. Similar to Piaget, Vygotsky emphasized that make-believe play serves as a primary driver of socio-cognitive advancement. During these activities, children between the ages of one and three often verbalize their actions; this "private speech" serves as a self-regulatory tool that eventually becomes internalized as cognitive thought.

Key Linguistic Transitions:

Social Speech: External communication used to interact with others.

Private Speech: Self-directed dialogue that assists in task completion and behavior regulation.

Inner Speech: The internalization of private speech, which facilitates silent, complex reflection.

2.1.4 Montessori's Educational Philosophy (Crain, 2010)

This philosophy is founded upon the principle that "if the child is prevented from enjoying these experiences [acquisition of language, use of hands, socializing, play] at the very time when nature has planned for her to do so, the special sensitivity which draws her to them will vanish with disturbing effect" (Montessori, 1949). Consequently, child development is categorized into sensitive periods, during which children must engage in specific experiences to ensure a healthy developmental cycle.

The Five Sensitive Periods

1. Order (0–3 years): The child possesses an innate yearning for order and consistently seeks to place objects where they "belong."
2. Details (1–2 years): The child focuses intently on minute details within their environment.
3. Use of Hands:
18 months – 3 years: Children constantly grasp objects and find satisfaction in opening and closing items.
2 years – 4 years: Children refine motor movements and the sense of touch, often enjoying the identification of objects with their eyes closed.

4. Walking: Toddlers engage in walking for its own sake rather than as a means to reach a specific destination.
5. Language (0–3 years): A period of heightened sensitivity where language acquisition occurs through biological imprinting.

Building upon these periods, the theory suggests that children should be granted the opportunity to pursue what they find most valuable. By allowing spontaneity to guide them, a child's power of observation is amplified when they interact with materials that meet deep, internal needs. Montessori observed that in such instances, children exhibit profound concentration. Accordingly, she advocated for free choice for children aged 0–4, enabling them to select their own activities. By age six, children develop a desire to understand the mechanics of the external world and seek mastery over their surroundings.

The philosophy further elaborates on the task of drawing. Montessori contended that children strive to draw as precisely as possible. To foster genuine creativity, educators must help children refine their powers of discrimination—focusing not on "free drawing," but on the deliberate distinction between various forms and colors.

2.1.5 Summary

These theories categorize various age groups and their specific cognitive development requirements. Consequently, it can be concluded that distinct age brackets necessitate different social and recreational conditions to satisfy evolving developmental needs. Keenan and Evans (2016) further emphasize that emotional development profoundly influences growth, as emotional expression reflects the maturation of socialization skills.

Infants and young children (0–4 years) acquire "emotional display rules" by observing parents and caregivers. During this stage, they rely heavily on social referencing, a process in which they utilize the emotional expressions of others to interpret situations that are too complex or abstract for independent comprehension. The capacity to process and display emotions evolves significantly during early childhood and the school-age years. (4–6 Years) Children typically experience and display only a single emotion at any given time. Their emotional focus is singular and lacks multifaceted nuance. (6–8 Years) Children begin to acknowledge two distinct emotions regarding a single situation. However, these emotions are processed in a sequential order rather than simultaneously; the child may transition from one feeling to another but cannot yet integrate them into a singular, complex experience.

2.2 Play and Creativity

Humans utilize play to explore creativity and transcend the pragmatic constraints of work and reality. This “excess mental energy” is channeled into the creation of aesthetics or pleasurable activities that facilitate higher-order thinking (Frost et al., 2012). Friedrich von Schiller contended that play represents the surplus energy from which all creative, artistic, and spiritual endeavors emerge. To develop engaging play, one must seek novel environments, objects, and contexts that necessitate a cognitive refocusing. This is essential, as play serves as the primary vehicle for learning during childhood, compelling the child’s cognition to move beyond concrete experience toward abstraction. In this context, creativity manifests through originality, fluidity, the “flow” experience, and intellectual engagement.

The quality of play is determined by its constructive or destructive nature. Frost et al. (2012) define “good” (enabling or constructive) play as inherently creative. Conversely, “bad” (disabling or destructive) play is characterized as narrow, unimaginative, uninspiring, or cruel. Play occupies a significantly more vital role in cognitive development than historical assumptions suggested. However, contemporary trends indicate that many children have become accustomed to passive entertainment via digital screens; this shift may lead to social maladjustment, diminishing the capacity for intelligent human interaction and creative industry.

According to Keenan & Evans, (2016) there are the following types of play in children:

- Solitary Play: Children play by themselves in way different style than others.
- Unoccupied Play: Child simply watches and observes what interests them.
- Onlooker: Child looks at other children play, while talking to them but not participating.
- Parallel Play: The children play beside each other.
- Associative Play: The children talk to each other and share same materials but do not share the same imaginary context. This is most common for children of 3-4 years.
- Cooperative Play: Where all the children take part proactively. For example, formal games, social pretend play, constructive play. Although this is rare before 3 years.

Not all types of these play invoke social interactions. Most important for the context of this project is cooperative play and associative play. Where children can exchange ideas and thoughts while playing and can get inspired by each other. Here the social robotic system can intervene as a facilitator to move the children from other types of play to a social type of play. Depending on the age, the type of play, the materials, the method of play, the cognitive development and motor skills change and evolve.

In the book, Play & Child Development, they have divided this into following three major blocks:

2.2.1 Play in Early Childhood (0-2 years)

The responsible adult—whether a parent, caregiver, or teacher—facilitates play activities during this developmental period. Gross motor skills emerge early as the toddler strives for full mobility; by age two, children are typically capable of climbing stairs and running outdoors. Fine motor skills, concerning the control of arms and hands, develop more gradually. The initial skill to emerge is the ability to grasp, followed by the capacity to transfer objects between hands, hold items simultaneously in both hands, clap, and scribble. During the first year, infants engage in play with their own bodies, such as their fingers and toes, before utilizing picking and grasping to interact with external objects.

A prevalent phenomenon observed is the “explore then play” sequence; infants often defer play until exploration is finalized. Play typically occurs only within a familiar environment. Initially, a toddler may explore an object by striking it against the ground or examining it with their mouth and tongue. Play commences only once the child understands the properties of the object—specifically, what actions the object permits. Thus, exploration serves as the necessary precursor to play.

Following the first twelve months, object permanence emerges, facilitating the transition to symbolic play. This form of play serves as a critical foundation for literacy development and can be actively promoted by adult facilitators. Functional play appears during the sensorimotor phase (approximately 24 months); the primary level involves the practice of repetitive behaviors. Such repetition is inherently pleasurable, and children continue these actions until mastery is achieved. Furthermore, infants possess an innate social drive, as a significant achievement during the first two years is the development of the self, including self-recognition and self-control. Within this context, toys facilitate social interaction as they are offered to and accepted by peers.

When toddlers engage in play, they are using imaginations to create or replicate a role. Toddlers can engage in art, music, dramatic play & aesthetic appreciation in their expressions of creativity.

Art: Toddlers use pencils, crayons, markers, & finger paints. Explore play with dough, glue & scrap materials to construct their art.

Music: Bouncy music can encourage them to engage in creative movement.

Dramatic Play: Experiences with dramatic play expand possibilities for pretending.

Aesthetic Appreciation: Experiencing expressive arts, sensory activities, books, listening to music, singing songs and enjoying natural elements.

Based on the observations, (Frost et. al, 2012) have outlined the following toys guidelines for successful play in this age group.

1. Toys should be appropriate for child's development.
2. Toys should be safe & durable.
3. Toys should complement child's ability to grasp and manipulate.
4. Toys should appeal to child's senses.



Figure 1: Children's Developmental Needs - KidsPressMagazine.com, 2014

2.2.2 Play in Preschool Years (2-7 years)

During this stage, children enter the fundamental movement phase, gaining enhanced control over gross motor skills such as running, jumping, throwing, and catching. Between the ages of three and five, they refine their fine motor skills, acquiring the finger dexterity necessary to become proficient in tasks such as assembling puzzles, using scissors, manipulating small blocks, and modeling clay.

Additionally, children begin to develop perceptual motor skills, which include:

Body Awareness: Understanding the parts of the body and their functions.

Spatial Awareness: Perceiving the body's position in relation to the environment.

Directional Awareness: Developing concepts of left, right, up, and down.

Temporal Awareness: Understanding rhythm and the passage of time.

Regarding cognitive development, children aged two to four occupy the symbolic function substage, characterized by egocentrism. In contrast, those aged four to seven move into the intuitive thought substage, marked by a shift toward more complex reasoning, though still limited by centration.

During this period, object play increases in complexity, frequently incorporating construction play. Block play reaches its peak; providing children with specific themes can foster guided creativity. By ages five and six, these constructions become increasingly elaborate through social interactions, as children exchange ideas and strategies. However, contemporary children often demonstrate diminished proficiency in these higher levels of social play.

Preschoolers exhibit creativity through speech, role-play, and the use of classroom materials such as art, music, and large-scale constructions. Research by Lieberman (1965) suggests a correlation between playfulness and higher levels of creativity. Engaging in social fantasy play and divergent thinking tasks allows children to generate a wide variety of ideas. Furthermore, play with unstructured materials fosters imagination, while social play proves particularly beneficial for creative development. Creative children often display heightened sensitivity to internal and external stimuli and a lack of inhibition, utilizing imagination and fantasy uniquely. A significant concern for the current preschool generation is the tendency to rely on digital screens rather than conceiving

original ideas and expressing personal creativity (Almon et. al, 2009).

2.2.3 Play in Elementary School (8-11 years)

After the age of seven, children begin to engage in complex constructions, such as building detailed model aircraft. During this period, writing skills advance toward the mastery of cursive script. These children possess distinct cognitive developmental traits that differ significantly from those of preschoolers; they utilize cognitive resources for planning, become cognizant of their intellectual abilities, and can identify their personal strengths and weaknesses. Their capacity for concentration is also markedly higher.

School-age children develop concrete operational thought, allowing them to apply logical methods to actions and utilize selective attention during play. At this stage, games with rules—both collaborative and competitive—emerge as a primary form of engagement.

Creativity during the school years is expressed through diverse mediums, including painting, photography, musical performance, dramatic composition, computer programming, and dance. Children at this age are characterized as eager inventors and confident artists. Notably, block play facilitates invention to such an extent that blocks are frequently termed “super toys.” Open-ended play activities foster ideational fluency, enabling children to generate a greater number of solutions to challenging problems.

However, formal school environments may inadvertently suppress creativity through an intense focus on standardized curricula. Such environments often prioritize convergent thinking over divergent thinking, placing an overemphasis on conformity and the strict adherence to directions.

2.3 Child-Robot Interaction (CRI)

In the domain of Human–Robot Interaction (HRI), there is growing research within the sub-domain of Child–Robot Interaction (CRI), as the philosophy and modes of interaction with children differ significantly from those with adults. Addressing CRI therefore requires designing through a combination of both a robot-centred perspective (what robots can do) and a child-centered perspective (what children gain from the robot and how the robot should socially interact with them) (Rudenko et al., 2024).

Humans inherently interact in social ways, meaning that behaviour is contingent on the actions of those around us. Consequently, if robots are to interact effectively with human users, they must be able to process their social surroundings and act appropriately with respect to context (Belpaeme et al., 2013b). Robots are generally perceived by children as entities positioned somewhere between living and non-living, which challenges children's developing understanding of the world (Torpegaard et al., 2021). However, children show a higher tendency than adults to anthropomorphize robots and are more capable of engaging with them as life-like agents (Belpaeme et al., 2013). There are two ways of conceptualizing social robots: first, that robots should continuously read and adapt to human emotional needs; and second, that a robot's social agency exists primarily in human perception, regardless of the robot's actual ability to perceive the human (Torpegaard et al., 2021).

There is high potential for CRI applications to produce positive, immediate, and measurable impacts on children. One of the main application areas is the design of social robots for children. A large number of robots are currently created for educational purposes, representing one of the newest trends in classrooms from kindergarten through high school, where they aim to provide children with practical and hands-on exposure to technology (Papadakis, 2020). Much of the existing research also focuses on social robots designed for children with mental or developmental disabilities, exploring how robots can help children overcome social difficulties without judgment. However, children's needs and demands continuously change as they grow, which implies that robotic capabilities should also adapt to these changing requirements. At present, there remains a significant gap in the design of real-world social robots

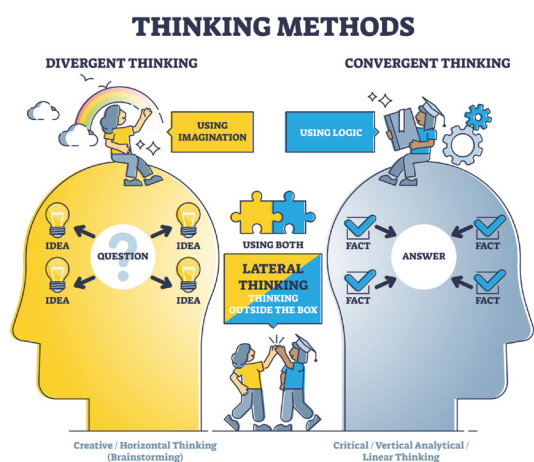


Figure 2: Thinking Methods: Divergent vs. Convergent

that can support meaningful long-term interactions with children (Chen et al., 2025).

To support long-term social interaction, it is essential that robots consider both the specific semantic task and the shared interaction history. Projects such as the ALIZ-E project have implemented expressive robot gestures to enhance social interaction (Belpaeme et al., 2013). Going further, robots should be designed with multimodal perception modules to robustly support complex CRI use cases (Efthymiou et al., 2022). Robots must be able to perceive and interpret the multiple modalities humans use to communicate. However, most existing social robots rely on limited modalities, forcing users to adapt to the robot's perception capabilities rather than the robot adapting to the user. To keep children engaged and entertained, it is therefore necessary to create integrated robotic systems capable of a broad range of perceptual and actuation abilities (Efthymiou et al., 2022).

Social robots also have strong potential as creativity-facilitating tools for children within collaborative interactions. Children are inherently creative, often displaying novel and unexpected ways of understanding the world. (Howard-Jones et al., 2002) However, as educational curricula become increasingly structured and rigid, opportunities for creative play—an essential component of childhood development—are often reduced (Ali et al., 2021). In an ever-changing world shaped by advances in AI and technology, children should be empowered to interact with novel social robots not merely as learning tools, but as creative partners capable of supporting the generation of new artefacts and approaches to problem-solving.

One of the major challenges within CRI is its intrinsically multidisciplinary nature, combining human-oriented objectives with the technical challenge of engineering robots to support these goals (Rudenko et al., 2024). While state-of-the-art social robots are often capable of engaging children in short-term interaction scenarios, they largely fail to sustain engagement over extended periods of time.

To address this limitation, some studies have proposed the idea of robots that can evolve alongside children as they grow. The paper *Robots that Evolve with Us* (Chen et al., 2025) explores modularity as a strategy for creating sustainable, long-term robotic companions. The authors demonstrate that modularity can enable personalization, support adaptability across changing life-stage needs, and promote sustainability through repair, reuse, and continuity. Within this framework, robots can be envisioned as long-term companions that support children's play needs throughout different stages of childhood.

The study proposes the following design principles to enable long-term robot use:

- Support inclusive personalization across life stages
- Provide open platforms for co-creation
- Design for adaptability within and across life stages
- Foster sustainability as both a material and emotional practice
- Embrace modularity as a mechanism for lifespan-centered design

In comparison, Torpegaard et al. propose four design implications specifically for social robots for preschool children: design for open play, design with emotions and personality, keep interactions simple, and design for durability. Designing modular robots for educational contexts has also presented numerous challenges, highlighting the need for novel, modular, and open-source robotic platforms (Chatzopoulos et al., 2022). Current educational robots often suffer from several limitations: (1) high cost, (2) limited expandability in terms of actuators and sensors, (3) reliance on proprietary software and hardware, and (4) dependence on continuous internet connectivity.

2.4 Evaluation of Creativity

Creativity is most commonly defined by two criteria: a creative act or product must be both original (novel) and effective (appropriate or meaningful in its context) (Runco & Jaeger, 2012). This standard definition, however, is calibrated to publicly recognisable creative products and does not provide the right framework to work with the creative expressions of a two- to eleven-year-old child. This thesis therefore adopts the lens of mini-c creativity – “the novel and personally meaningful interpretation of experiences, actions, and events” (Kaufman & Beghetto, 2009). Mini-c shifts the emphasis from creative expression, judged against external standards, to creative interpretation and ideation as it occurs within the individual, foregrounding the intrapersonal, process-focused “beginner’s mind” qualities – openness, active observation, and a willingness to explore the unknown – that characterise a child at play. This framing is grounded in Vygotsky’s account of imagination, for whom “any human act that gives rise to something new is referred to as a creative act, regardless of whether what is created is a physical object or some mental or

emotional construct" (Vygotsky, 2004). Vygotsky held creativity to be fundamentally combinational: rather than merely reproducing experience, the child reworks and reorganises prior impressions into something new. Crucially, this imaginative activity "operates in a particular way" at each stage of childhood, which directly motivates the age-adaptive approach taken in this project.

Accordingly, creativity in this thesis is evaluated not as the objective quality of a finished artwork but as the child's original, personally meaningful engagement in the act of drawing: whether the child explores beyond the familiar, generates and transforms ideas, builds on them in their own way, and remains the author of an artefact that is new and meaningful to them.

Creativity is a very subjective domain when judging but even then there are several scientific scales that have been developed to measure creativity for particular activities. For the context of this project, it was decided to explore further with one of these scales which could prove to be essential when conducting the research experiment with the social robotic system prototype. As previously mentioned, different age groups require different materials and toys to participate in creative activities. Even in the creative activities, they require different social triggers and nudges to further keep them engaged in activities. The focus of this research will be on designing a drawing social robotic system to enhance their artistic expression with play. In order to assess the creativity; the following scale will be explored during the prototyping phase: Test for Creative Thinking – Drawing Production (TCT-DP) (Urban 2009).

TCT-DP assess the creativity in drawings and artistic expression. The test includes the following factors which are scored for each artwork and the tally totaled:

- I.Continuations (Cn):** Any use, continuation or extension of the six given figural fragments.
- II.Completion (Cm):** Any additions, completions, complements, supplements made to the used, continued or extended figural fragments
- III.New elements (Ne):** Any new figure, symbol or element.
- IV.Connections made with a line (Cl)** between one figural fragment or figure or another.
- V.Connections made to produce a theme (Cth):** Any figure contributing to a compositional theme or "gestalt".
- VI.Boundary breaking that is fragment dependent (Bfd):** Any use, continuation or extension of the "small open square" located outside the square frame.
- VII.Boundary breaking that is fragment independent (Bfi).**

VIII.Perspective (Pe): Any breaking away from two-dimensionality.

IX.Humour and affectivity (Hu): Any drawing which elicits a humorous response, shows affection, emotion, or strong expressive power.

X.Unconventionality, a (Uc, a): Any manipulation of the material.

XI.Unconventionality, b (Uc, b): Any surrealistic, fictional and/or abstract elements or drawings.

XII.Unconventionality, c (Uc, c): Any usage of symbols or signs.

XIII.Unconventionality, d (Uc, d): Unconventional use of given fragments.

XIV.Speed (Sp): A breakdown of points, beyond a certain score-limit, according to the time spent on the drawing production.

However, as with all creativity tests, TCT-DP has some limitations and should be used in conjunction with other information (such as another creative test, teacher's views, parent's views) in order to minimize false negatives. This would mean missing creative children whose variety of creativity is different than that measured by a single test. To overcome this limitation, the teacher of the children will be interviewed for analysis of the experiment to further validate the results of the findings.

2.5 State of Art (Creative Social Robot Systems)

This section serves as a benchmark for the technologies that already exist in this domain. The following examples demonstrate that creative Child-Robot Collaboration is possible, making it a growing and novel field within which this research is situated. Together, they provide inspiration for ideation and illustrate the possible use cases of a robotic system.

These concepts showcase the diverse modalities and creative activities that robotic systems make possible in co-creation. They also reveal the varied roles that the robot and human agents can take, and how these roles shift depending on the design of the workflow.

YOLO (Alves-Oliveira, et. al 2018)– Your Own Living Object is a child co-designed robot which uses personality as the basis for the robot's social behavior to provoke more story-lines when children play with the robot. The robot can be moved by the children during a live drama enactment and act as an conversational agent to give them triggers in the making their storytelling creative and social.



Figure 3: YOLO Robot, Alves-Oliveira et. al 2018

JIBO Drawing Game (Ali et. al, 2021) – Using the social robot JIBO, the researcher here created doodle creativity game where the child and robot collaborate on a tablet to draw and have a conversation to share their ideas. The research concentrated on 8-9 years old to investigate their engagement and creativity with a social robot.

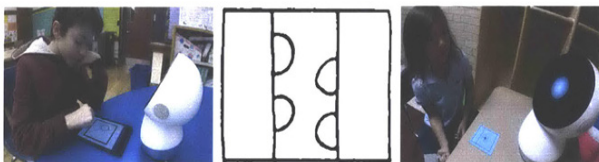


Figure 4: JIBO Drawing Game, Ali et. al 2021

Doodlebot (Williams et. al, 2024)– A social robot designed for classroom use as a programmable and interactive educational robot which can be used for teaching AI concepts. The doodlebot is capable of collaboratively producing generative drawing that focuses on developing students' creativity skills and enabling their creative collaboration with generative AI.

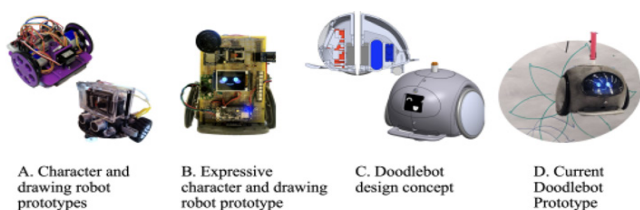


Figure 5: Doodlebot, Williams et. al, 2024

Cobbie (Lin et. al, 2020)– A robot which can take part collaborative ideation with designers through sketch. The user first must sketch on the paper, then the robot captures the image of the sketch and working area. Then the robot generates ideas to finish the sketch by drawing on the already sketched part with the designer. There are some pre-defined shapes and objects which it can reproduce by matching them with the user input sketch.

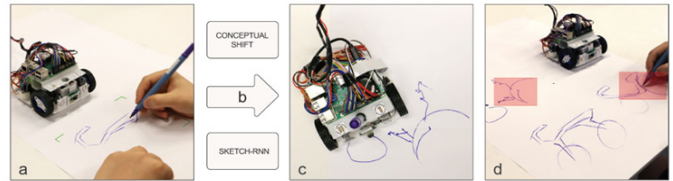


Figure 6: Cobbie robot, Lin et. al 2020

HARU (Gomez et. al, 2018)– Developed by the Honda Research Institute Japan, HARU is a tabletop social robot designed around empathy and emotional connection rather than task completion. It communicates almost entirely non-verbally: it conveys emotion through the gaze and movement of its expressive eyes, leans in to show interest or pulls back when startled across five degrees of motion, and reinforces these gestures with a custom suite of sounds. With a distinct, animation-inspired personality and backstory, it has been used for interactive storytelling, creative collaboration, and educational play with children. HARU is a strong example of how a robot can build rapport and engage children through embodied, multimodal expression – eyes, posture, and sound – rather than verbal instruction.



Figure 7: HARU Robot, Gomez et. al 2018

INDRA (Nakagawa et. al, 2024) – Developed at Keio University's Embodied Media Lab, INDRA (Interactive Deep-Dreaming Robotic Artist) is a robotic arm that paints collaboratively with a person in a turn-based session, the human and robot swapping roles via a chess-clock button. It passively listens to the painter's ambient speech, which subtly influences the painting's outcome, and is explicitly designed as an "artist-friendly" agent that balances automation with meaningful human control.



Figure 8: INDRA, Nakagawa et. al 2024

Modulo Cellulo (Khodr et. al, 2022) – Developed at EPFL, Modulo Cellulo is the modular evolution of Cellulo, a versatile handheld tangible robot for learning that is rooted in Papert’s Logo Turtle and Piaget’s constructivism – a “computational object to think with.” Its modular design (a main, battery, and interaction module) broadens the robot’s functions and robustness, and it can even incorporate reconfigurable robots as additional modules to enable collaborative swarm activities. It is relevant both for its tangible, constructivist approach to children’s learning and for demonstrating how modularity extends a robot’s versatility and lifespan – a key concern in designing robots that grow with the child.

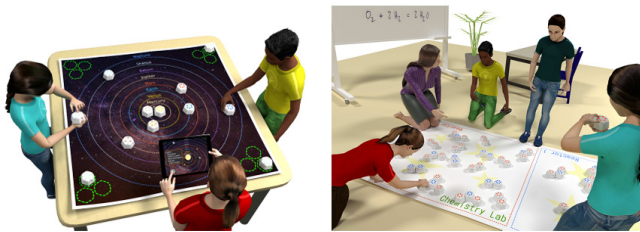


Figure 9: Modulo Cellulo, Khodr et. al 2022

ELEGNT (Hu et. al, 2025) – Developed at Apple, ELEGNT (Expressive and Functional Movement Design for Non-anthropomorphic Robots) argues that a robot’s movement should do more than reach a goal efficiently; it should also express the robot’s internal states – intention, attention, attitude, and emotion – through “expression-driven” trajectories. Studying a non-humanoid, lamp-like robot, it shows how posture, gesture, and gaze can make even a non-anthropomorphic machine communicate naturally and legibly. This work directly underpins the expressive embodiment of this project, where a non-humanoid robot conveys each personality’s intent through the movement of its eyes and body rather than through speech.

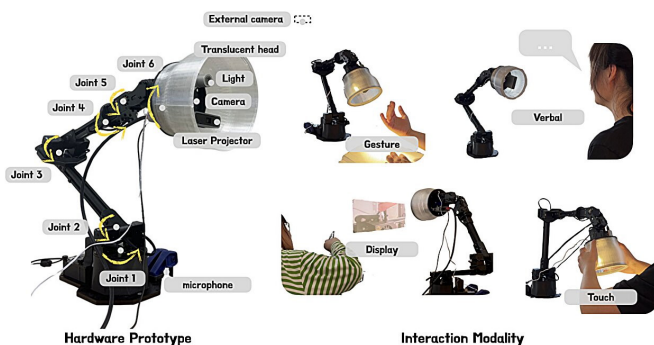


Figure 10: ELEGNT Robot, Hu et. al 2025

Robotic Canvas (Alhafnawi et. al, 2020)– Developed at the University of Bristol, Robotic Canvas turns a swarm of around 200 decentralised robots into the pixels of a living canvas that a person can paint onto through physical gestures, across six distinct “Painting Modes.” The resulting artwork emerges from the interplay between the robots, their environment, and the human performer, making art-making a collaborative, immersive performance rather than a solitary act. It is a direct precedent for the “robot as canvas” and multi-robot concepts explored in this project, showing how emergent, collaborative creativity can arise from human input acting on a swarm of robotic agents.

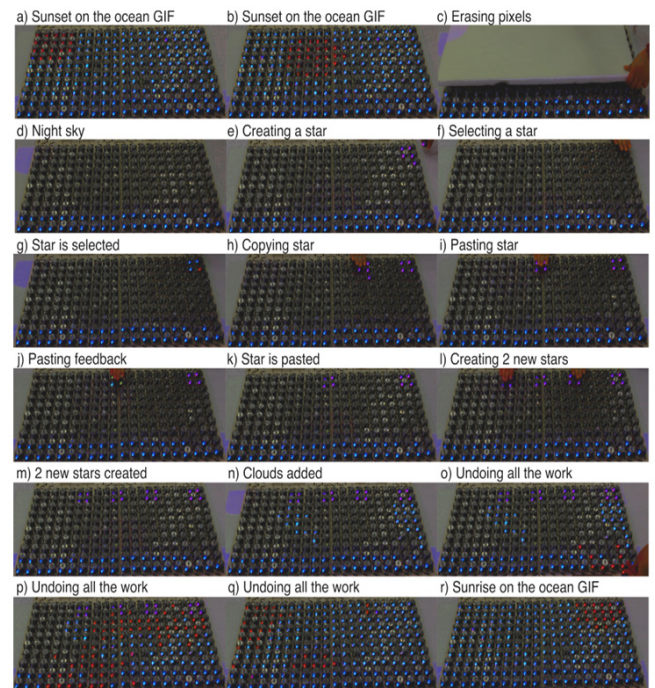


Figure 11: Robotic Canvas, Alhafnawi et. al, 2020

Taken together, these projects show that Child-Robot Collaboration is not only feasible but can take many forms – from conversational prompting (YOLO, JIBO) and turn-based co-sketching (Cobbie, INDRA), and expressive, non-verbal companions whose movement conveys intent and emotion (HARU, ELEGNT). Across this diversity, several recurring qualities stand out. The robot acting as a creative prompt or partner rather than an instructor; the preservation of the human’s agency and authorship over the work; and the power of legible, non-verbal expression (gaze, posture, and gesture) to build rapport without relying on speech. Yet the same body of work also exposes some of the gaps this project sets out to address: most of these systems are built around a single creative modality and a narrow age range, and few adapt their behaviour, complexity, or role as the child develops.

2.6 Participatory Design with Children

Participatory design is a collaborative design approach that involves end-users directly in the design process, treating them not as subjects to be studied but as partners and experts in their own experience. Its aim is to create products and services that better meet users' needs and expectations by drawing on their own knowledge, practices, and lived experiences (What Is Participatory Design?, 2026). This is especially valuable when the end users differ markedly from the designer – as is the case with young children, whose preferences, social behaviours, and ways of engaging with technology cannot be fully anticipated through observation or theory alone. Within the context of this project, the co-design sessions go beyond simply giving children a voice in design; they address the broader aim of empowering children to shape the technological development that will increasingly surround them, and to critically reflect on the role of technologies such as robots and AI (Iversen et al., 2017).

Because children are the intended end users, the design process will include co-design workshops with them, which are essential for gaining insight into the robot's desired social behaviour across the different age groups. When facilitated through a well-structured and carefully planned session, children can serve as valuable co-researchers rather than passive participants, surfacing ideas and expectations that an adult designer might otherwise overlook. The project will involve children in two stages. In the first, during the ideation-convergence phase, a co-design workshop will focus on identifying the key social behaviours the robot should exhibit for each age group, grounding the design requirements in the children's own input (Klapwijk et al., 2021). In the second, the prototype will be evaluated by observing and analysing the children's creative artefacts and their social interactions during use, testing whether the intended behaviours translate into genuine engagement. Both workshops were designed around the principles set out in the Co-design With Kids toolkit (Co-design With Kids – a Toolkit for Designers, n.d.) to ensure the sessions are age-appropriate and gather meaningful information and insights.



Figure 12: Co-Design session with children for Haru Robot, (Gomez et. al, 2018)

2.7 Key Findings

Here is the summary of the main findings from the literature review.

Child Cognitive Development & Play Evolve with Age Developmental Stages

A child's cognitive, emotional, and social needs change drastically as they grow. Educational frameworks (Erikson, Piaget, Vygotsky, Montessori) emphasize that activities and resources must match these developmental stages to foster autonomy, initiative, and industry.

The Trajectory of Play

Play progresses from physical exploration and functional repetition (0-2 years) to complex construction and symbolic/pretend play (2-4 years), (5-7 years) and finally to rule-based, logical, and divergent thinking activities (8-11 years).

Social Play is Crucial

Cooperative and associative play (most common from age 3 onward) are critical for exchanging ideas and inspiring creativity. A social robot can act as a facilitator to transition children from solitary or parallel play into these highly creative social states.

The Digital Generation

There is a growing concern that modern digital entertainment (screens) is stunting divergent thinking, imaginative play, and the development of warm social interactions.

Anthropomorphism

Children are much more likely than adults to view robots as life-like, social agents, making them highly receptive to robotic interactions.

The Longevity Gap

A major flaw in current state-of-the-art social robots is their inability to sustain long-term engagement. Children's needs constantly change, but robots typically remain static.

Evolving Design

To support long-term companionship, robots must be adaptable. Utilizing modularity, open play concepts, durability, and a personality that evolves with the child's life stages are key design principles for success.

Multimodal Perception

Robots need to move beyond limited perception and adapt to how children naturally communicate (multimodal inputs) rather than forcing the child to adapt to the robot's limitations.

Robots as Collaborative Creative Partners Beyond Educational Tools

In an AI-driven world, robots should not just be passive educational devices. They hold potential as collaborative partners that actively participate in the generation of new artifacts and problem-solving.

State of the Art Context

Existing projects (YOLO, JIBO Drawing Game, Doodlebot, Cobbie) demonstrate that robots can successfully engage children in collaborative storytelling, generative drawing, and co-sketching by serving as conversational and creative prompts.

Creativity is a Process, Not a Product

For a young child, creativity lies less in the polish of a finished artwork than in the act itself – the original, personally meaningful reworking of experience into something new. Creativity-scoring instruments such as the TCT-DP still offer a useful, structured way to assess creativity in a drawing, and are evaluated further in this project.

Evaluating Creative Process

Because a young child's creativity is intrapersonal and in-the-moment, it is best understood qualitatively. That is through their engagement, choices, and willingness to explore the unknown while drawing. This project therefore treats creativity as the child's original, personally meaningful engagement with the task.

The Necessity of Participatory Design

Children as Co-Researchers: Designing an age-adaptive robot requires directly involving the end-users. Participatory co-design empowers children to shape the technology and ensures the robot's social behaviors align with their actual expectations.

Two-Stage Implementation

The design process should involve children during the initial ideation phase (to identify key social behaviors per age group) and during the validation phase (to test the prototype's impact on their creative output).

3. Expert Interviews with Teachers

3.1 Interview with Teachers

3.2 Thematic Analysis

3.3 Key Findings

3.1 Interview with Teachers

The literature review established a theoretical understanding for how children's cognitive, social and creative capacities evolve across early and later childhood, and how a social robot might, in principle, support creative play. What it could not provide, however, was a grounded, real-world picture of how those principles actually surface in children's day-to-day creative activity, how engagement, collaboration and the need for adult nudging genuinely differ between a two-year-old and an eleven-year-old. This section set out to close that gap. The driving curiosity was a practical one: across the three age brackets, what creative activities engage children, how do their collaborative dynamics differ, what role does a facilitator play, and how might that role be taken up by a social robot?

Teachers were chosen as the expert source because they sit precisely at the intersection of theory and practice the project needs to understand. They observe many children across exactly these developmental stages, every day and over long periods; they are skilled at managing group dynamics and they already perform, in person, the scaffolding, mediating and "sparking" role for the children during classes. Where the literature offers general developmental principles, teachers can speak to concrete, real world examples of behaviour –which nudges actually work for a given age, what is hardest to manage, and what they would and would not want a robot to do. In this sense the interviews complement and extend the previous chapter. The interview with teachers can move the enquiry from secondary, literature-based theory to primary, expert observation, translating broad developmental principles into the age-specific, practice-grounded insights.

Semi-structured interviews were conducted with five school teachers (two from group [2-4 years], one from group [5-7 years], & two from group [8-11 years]), and the responses were thematically analysed to explore age-related social and creative differences among children. The findings were subsequently used to inform the design of the robot's functionality and social behaviour. Below is the framework of the interview conducted and the themes that will be coded for analysis.

1. What are the kinds of creative activity that the children from your age group take part in?

- a. Can you walk me through a one of the recent activity you saw?
- b. How do children behave during these activities?
 - i. When are they most engaged?
 - ii. When do they lose interest?
 - iii. Do you feel a need to provide them nudges?
 - iv. If yes, what are the nudges or feedback you give them?
- c. Is there any particular activity that you feel can benefit from becoming more social?

2. Do children collaborate during these activities?

- a. What does the collaboration look like?
- b. What are the social dynamics like during this? Do some children dominate, while others go in their shell?
- c. Do conflicts happen?
- d. What are some of the non-verbal communication you have noticed?, if any.

3. Can you recall a moment where children were deeply engaged in building or creating something together?

4. What is your role during these activities?

- a. When do you intervene?
- b. How do you intervene?
- c. What are the hardest moments to manage?
- d. What do you wish you had more support with?

5. What kind of playing activities do your children participate in?

a. Have you seen any change in trend in these activities over the past 5-10 years?

b. Has technology influenced how they play or create?

6. What are your opinions on some of the new generation of toys?

- a. Are there any toys or systems that support creativity particularly well?
- b. What makes them effective ?
- c. What do they lack?

7. Have you taught children from other age groups?

- a. What are some of the differences you noticed?
- b. What are some of the similarities you noticed?
- c. How does creative behaviour change?
- d. How does collaboration change?
- e. How does your role change?

8. I am going to provide you with some of the conceptual sketches of a social robot, what are your first impressions of these concepts?

- a. How do you imagine children interacting with this?
- b. What works well?
- c. What concerns you?
- d. In what scenarios would this be useful?

9. What would be your ideal robot to make to help children with creative tasks?

- a. What role should it play?
- b. What should it not do?

10. Any more comments or thoughts you have for the project?

3.2 Thematic Analysis

For further understanding the context, and to better design for children, expert interviews were conducted with teachers and thematically analyzed. The research followed an inductive reasoning, or a bottom-up approach, where the observations and insights made during this phase help inform design decisions. A major element of the project is the age-adaptiveness and how the social robot should change its behaviour and functions across different age groups. To investigate further into differences and similarities across age groups, 2 teachers from the age group (2-4 years), 1 teacher from the age group (5-7 years) and 2 teachers from the age group (8-11 years) were interviewed.

Steps of Thematic Analysis (Braun & Clarke, 2006)

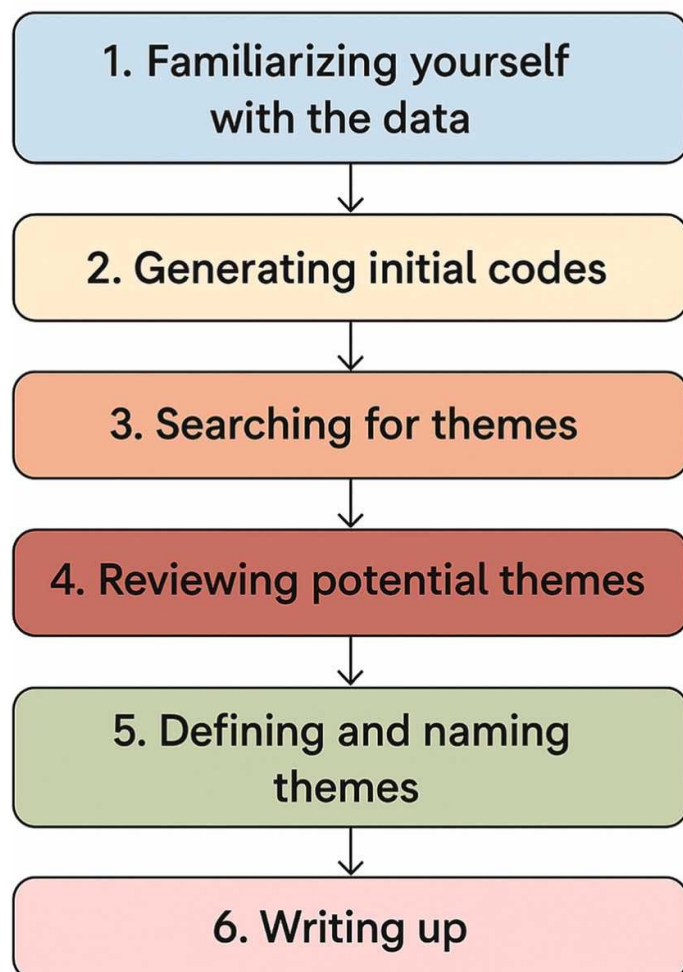


Figure 13: Steps of Thematic Analysis by Braun & Clarke 2006.

The interview data was then analysed using thematic analysis (TA), following Braun and Clarke's six-phase framework. TA was chosen for its structured yet flexible nature, which suits an inductive, bottom-up approach in which the themes emerge from the teachers' own accounts rather than from a pre-imposed coding scheme.

The analysis proceeded iteratively through the six phases: (1) familiarisation with the data, by repeatedly reviewing the recordings and notes from the five semi-structured interviews; (2) generating initial codes, working systematically through the responses to capture meaningful features, coded manually; (3) searching for themes, grouping related codes into broader patterns of meaning; (4) reviewing the themes against the coded extracts and the full dataset; (5) defining and naming them; and (6) writing them up.

In keeping with the reflexive character of TA, my own position as the researcher was treated as part of the interpretation rather than as a bias to be eliminated. This produced the following five themes: Creative Engagement, Dynamics of Collaboration, Facilitator's Role and Scaffolding, Impact of Digital Technologies, and Integration and Reception of Social Robots. Because age-adaptiveness was central to the project, the coded responses were additionally compared across the three age brackets. The overlapping quotes where teachers of different ages gave near-identical answers, and highlighting where their observations diverged, and the resulting themes were carried forward to inform the robot's design requirements.

3.2.1 Creative Engagement



Figure 14: Venn diagram of quotes of teachers from different age groups regarding creative engagement.

The figure 14 highlights teacher quotes from interviews regarding how children across specific age groups engage creatively. The data reveals clear distinctions in cognitive abilities based on age. For instance, young children (2-4 years) rely heavily on imitation in their art, whereas older children tend to draw from their own inspiration. The oldest group (8-11 years) has barely any free time for creative activities and tends to gravitate toward more complicated subjects. Surprisingly, both the youngest and oldest groups share a deep engagement in sensory activities, while the middle group (5-7 years) struggles to stay deeply engaged in a single activity and constantly needs novel experiences to refresh their focus.

During free play, both the youngest and middle groups usually juggle multiple creative activities, such as playing with LEGO, Play-Doh, and drawing materials. Ultimately, teachers across all age groups observe that children love hands-on problem-solving, and they actively encourage students to develop their own insights and inferences during these creative tasks.

3.2.2 Dynamics of Collaboration

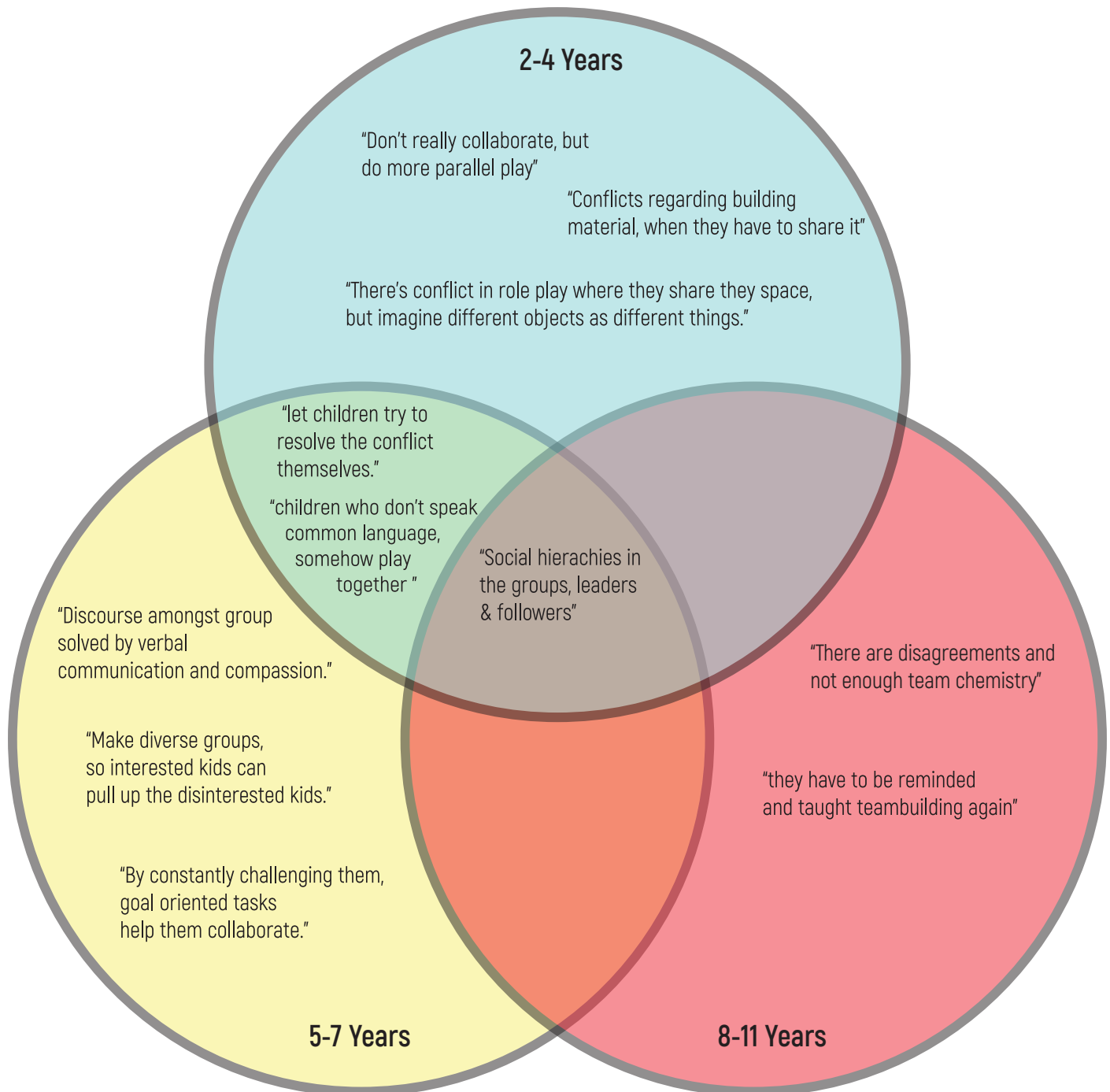


Figure 15: Venn diagram of quotes of teachers from different age groups regarding dynamics of collaboration.

The figure 15 highlights teacher quotes from interviews regarding collaboration dynamics across various age groups. The youngest group (2–4 years) generally does not collaborate, engaging instead in parallel play. However, conflicts frequently arise over limited materials, as the children struggle to share or take turns. In contrast, the middle group (5–7 years) is the most successful at participating in collaborative tasks. Teachers actively encourage this by creating diverse groups, allowing interested students to motivate their less-engaged peers to complete a task. Meanwhile, the oldest group (8–11 years) tends to consist of “lone wolves” who can be highly imposing with their ideas. Teachers note that this age group requires repeated instruction on team-building, as significant disagreements frequently occur, necessitating constant reminders about empathy. Despite these distinct differences, a universal trait across all three age groups is the formation of social hierarchies: natural leaders consistently emerge to dictate the vision for an activity, while the rest of the group follows.

3.2.3 Facilitator's Role & Scaffolding



Figure 16: Venn diagram of quotes of teachers from different age groups regarding facilitator's role and scaffolding.

The figure 16 highlights teacher quotes from interviews regarding their roles as facilitators and creative scaffolders. The teacher of the youngest group (2–4 years) acts as a mediator, resolving grievances by invoking compassion and encouraging children to put themselves in their peers' shoes. They scaffold the creative process by asking students to reflect on their work and develop their own insights. In contrast, teachers of the middle (5–7 years) and oldest (8–11 years) groups adopt a more hands-off, onlooker approach, typically only intervening if a situation escalates physically. However, the teacher of the middle group will still step in during collaborative projects to ensure everyone's ideas are incorporated. While the youngest and middle groups view the teacher as a major authority figure, this dynamic shifts significantly for the oldest group (8–11 years), who are less inclined to listen to authority. For this older demographic, the teacher's role during creative projects focuses instead on inviting outside experts to share their experiences and inspire the students. Despite these shifting dynamics, the teacher's primary, universal responsibility across all age groups remains acting as the main conflict solver.

3.2.4 Impact of Digital Technology



Figure 17: Venn diagram of quotes of teachers from different age groups regarding impact of digital technology.

The figure 17 highlights teacher quotes from interviews regarding the impact of digital technologies and recent behavioral trends in children. For the youngest group (2–4 years), teachers observe a lingering post-COVID impact on gross and fine motor skills, noting that these children have not yet developed the physical milestones expected for their age. The middle group (5–7 years) experiences some digital anxieties, occasionally becoming terrified by distant global events they read about online, despite being in no actual danger. Meanwhile, the oldest group (8–11 years) is described as nearly impossible to entertain or keep engaged, as they prefer to work independently. Interestingly, this older group frequently suffers from "analysis paralysis", they become so overwhelmed by their abundance of ideas that they cannot figure out how to take the first step in a creative activity.. Driven by their constant exposure to digital media and endless virtual options, both the youngest and middle groups (2–7 years) will refuse to try an activity if they are not immediately interested. Conversely, the middle and oldest groups (5–11 years) benefit from increased access to digital knowledge and are highly informed about the world. However, this comes at the cost of their attention spans, which is just about 20 to 30 minutes. iPads are the only digital technology permitted in the school, and their use is restricted entirely to educational games.

3.2.5 Integration & Reception of Social Robots



Figure 18: Venn diagram of quotes of teachers from different age groups regarding integration & reception of social robots.

The figure 18 highlights teacher quotes from interviews regarding the integration and reception of social robots. During the interviews, teachers were prompted with conceptual sketches of robots (figures 19-26), and their responses are represented. For the youngest group (2–4 years), teachers felt the ideal robot would act as an additional educator, specifically providing attention and feedback to the “unnoticed” children. For the oldest group (8–11 years), a robot capable of sparking ideas and helping them initiate activities was seen as a plus. They also reacted positively to the robots which enabled hands-on experience with physical materials. There were also distinct preferences shared between the age brackets. Teachers of the younger half (2–7 years) responded positively to the drawing robot, emphasizing that its workflow must involve a collaborative back-and-forth. Meanwhile, teachers of the older half (5–11 years) saw great potential in robots which could provide targeted feedback and push children past their fear of how or where to start. Interestingly, both the youngest and oldest groups (2–4 and 8–11 years) showed a strong, positive response to the broader concept of human-robot co-creation. Finally, a favorite across all age groups was the robot which could use its ability to facilitate sensory creativity such as the mouldable robot.

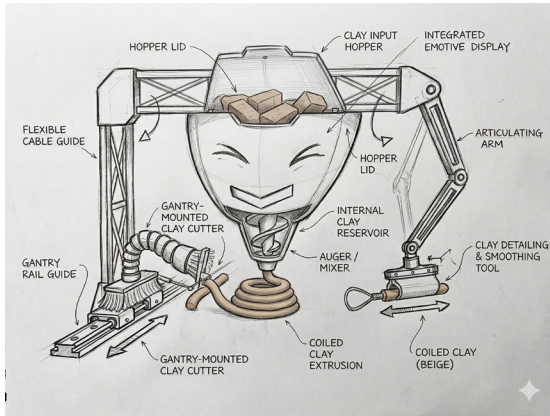


Figure 19: Clay Extruder Robot

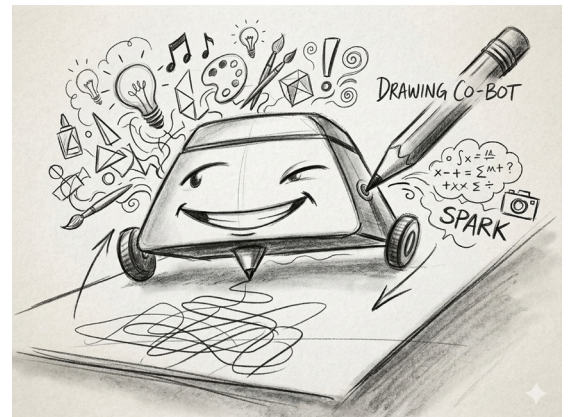


Figure 20: Drawing Co-Bot

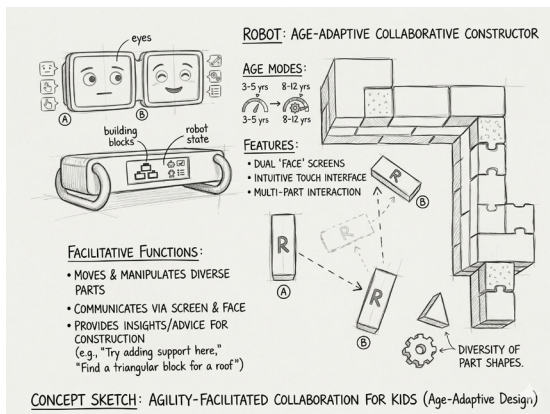


Figure 21: Collaborative Construction Buddy I

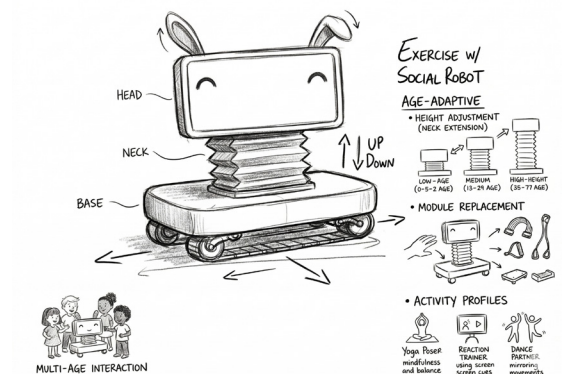


Figure 22: Exercising Co-Bot

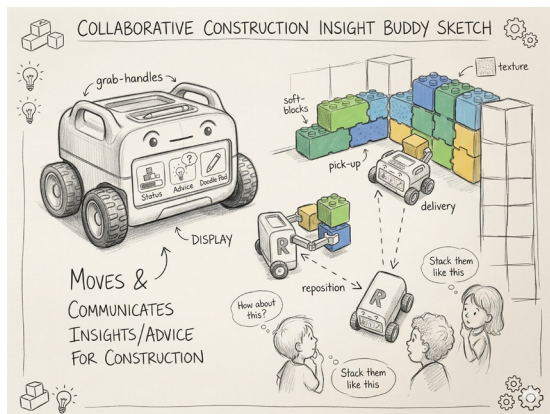


Figure 23: Collaborative Construction Buddy II

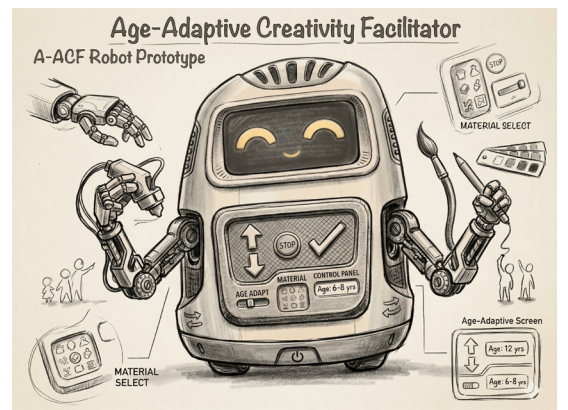


Figure 24: Drawing Assistant Bot



Figure 25: Drama Bot

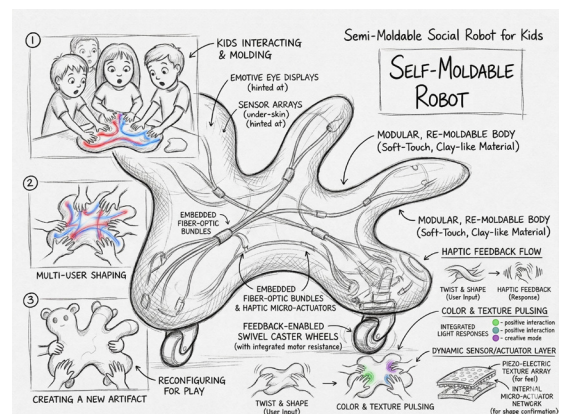


Figure 26: Mouldable Bot

3.3 Key Findings

1. Tactile and Sensory-Rich Hardware

Children across all age groups naturally gravitate toward hands-on problem-solving for creative expression. Because their current technological exposure is mostly limited to flat screens (which leads to quick disengagement) the robot must offer tangible, sensory experiences. For the youngest (2–4 years), this physical engagement is crucial to help in fine and gross motor skills, while older children need this physical complexity to remain creatively stimulated.

Requirement: The robot could incorporate physical, semi-mouldable components and support messy, hands-on interactions (such as a clay extruder, drawing mechanisms, or construction materials).

2. Co-Creative, “Back-and-Forth” Interaction Loop

Driven by high exposure to digital media, children across age groups show a refusal to try uninteresting tasks and suffer from short attention spans (maxing out at 20–30 minutes). A back-and-forth co-creation workflow prevents children from zoning out or letting the robot do the work for them. This workflow maintains their focus by requiring active, sustained participation to engage in creative tasks.

Requirement: The robot could function as a collaborative creative partner, requiring a continuous exchange of input and output between the child and the robot to progress the activity.

3. Multi-User Interface and Conflict Mitigation

Collaborative creativity is frequently hindered by group dynamics. Young children fight over limited materials during parallel play, while older children can form social hierarchies where imposing personalities dictate the group's vision. To successfully facilitate group creativity, the robot must act as an idea facilitator, able to pull ideas from everyone, ensuring all voices are incorporated into the final creation.

Requirement: The hardware and software could support multiple users simultaneously in a way that prevents domination from one single individual and actively prompts quieter users for their creative input.

4. Age-Adaptive Scaffolding and Personas

Because cognitive abilities, collaborative success, and attitudes toward feedback shift drastically as children age, the robot's software must feature three distinct, operational modes for each age group to successfully facilitate creativity:

Ages 2–4 (The Inspiring Mediator): For this age group, whose creative tasks are heavily based on imitation, the robot should act as an inspiring module. The robot should be capable of giving feedback nudges without imposing on child's free will. It should guide drawing and motor-skill tasks, while maintaining an empathetic persona to mediate disputes in tasks.

Ages 5–7 (The Collaboration Enhancer): This group is highly successful at collaboration but requires constant novelty to refresh their focus. The robot could focus on construction-based tasks that offer high variety. The robot should be capable of creating new goals and sub-activities within the given tasks to keep the engagement level high. It must actively monitor group dynamics and ensure every child's ideas are integrated into the creation.

Ages 8–11 (The Spark Catalyst): Because older children reject traditional authority and prefer to work independently, the robot must adopt a non-authoritarian “expert” or peer persona. Its primary function must be to act as an icebreaker, sparking initial ideas and pushing children directly into complex, hands-on tasks to overcome the “analysis paralysis” that frequently prevents them from taking the first step in a creative activity.

4. Co-Design/Creative Workshop

4.1 Co-Design Workshops

4.2 Construction Session (Role Play)

4.3 Collaborative Drawing Session

4.4 Design Insights

4.1 Co-Design Workshops

The primary goal of this phase of the project is to gain an understanding of user expectations and needs, the desired social interaction behaviors for the robot, and the collaborative dynamics among the users. To achieve this, a participatory design methodology was employed, consisting of two interactive workshops designed to gather qualitative design insights.

The workshops were held in a school setting to ensure the participants were in a comfortable, familiar environment, allowing them to fully engage with the activities.

A total of 43 children participated, divided into three age brackets: 10 children aged 2–4, 12 children aged 5–7, and 21 children aged 8–11. The workshops featured two distinct activities: a 'Co-Construction Role-Playing Session' and a 'Collaborative Drawing Session'. Participants worked in age-matched groups of three, which were randomly reshuffled between activities. The resulting data was then thematically analyzed to address predetermined research questions. Moving forward, these same participants will help evaluate the final design.

This section outlines the framework, structure and thematic analysis for the workshop sessions conducted.



4.2 Construction Session (Role Play)

RQ: What are the communication methods (excluding talking) that children use while engaged in creative play?

Object that can be a robot: sphere ball, box, puppet that one of them can move, imitating to be the robot. (I will inform them that they are the “helper”), collaborating with the other two children to ensure a coherent construction. Then have the participants role play in a creative construction exercise which would have one kid controlling the “object” and trying to communicate the ideas for construction to the other creators. They used LEGO blocks as part of the activity to construct their own creations.



Analysis of the workshop will be directed at answering the research question. The following observations will be recorded to get insights for design requirements of the robot.

1. What movements did the child controlling the ‘robot’ object make?
2. Was it easily understood by the other children while building?
if not, did it become easier as the session went on?
3. Did the robot intervention help make the collaboration successful?
4. Was the final construction creative and coherent?
5. What evidence of creativity stimulation occurred in the session?
6. How do the above observations vary across age group?

4.2.1 Thematic Analysis of Co-Creative Construction (Role Play) Session

The first activity of the workshops involved the Co-Construction Role-Playing Session, which explored the children's collaborative dynamics and social expectations. The qualitative data collected during this activity was thematically analyzed based on the study's predetermined research and observation questions. The following subsections outline these findings, categorizing the design insights by age group to highlight the developmental differences and similarities in how users expect to communicate and interact with the social robot.

4.2.2 Age Group (2-4 years)

For this age group, it was hard for them initially to grasp the idea of non-verbal communication and collaborate on construction, so in the beginning I had to provide them nudges and converse with them to get them excited to follow the rules of the activity.

1. What movements did the child controlling the 'robot' object make?

There was a lot of pointing and offering of blocks by the facilitator. Initially, they were all kind of building on their own, however, they started imitating each other's creation very soon. After nudging them further into building together, they started combining their ideas, they immediately understood actions of each other while building. Humming and sound effects played a big role in communicating their intent of what the construction required.

2. Was it easily understood by the other children while building? if not, did it become easier as the session went on?

The actions were in general easily understood by them and they already had a vision of what they were building together somehow. Their imaginative pretend play enabled them to envision concrete structures while creating abstract constructions. The communication definitely became easier as the session went and they could see what each other's creation and start imitating. Although, they had no verbal communication with each other, they still had a lot of think-aloud behaviour with themselves, for example "This block goes here, I need this, I make this big"

3. Did the robot intervention help make the collaboration successful?

The robot intervention did provide them with more



Figure 27: Imitation, one builds a tower another follows.



Figures 28a & 28b: Directly placing structures on top of creations without any verbal communication.



Figure 29: Pointing & signalling for the required block

incentive to work together and come up with innovative ways to communicate with each other. However, the most interesting observation was that the robot really helped shy kids to get more attention on their ideas (whether they were controlling the robot or were just building). They just needed someone to hear them and push them towards contributing.

4. Was the final construction creative and coherent?

Some groups had creative and coherent construction. As they started building on each other's creations. They made their own imaginary scenarios and enacted what the role of a specific part of the construction was and instinctively started building on each other.

5. What evidence of creativity stimulation occurred in the session?

As mentioned before, they were mostly getting inspired by each other or something they saw earlier during that day that they could construct. They had troubles making something they had never seen before. They were scaffolding on each other's creation. But eventually, it was also about who built the biggest thing or used a surprising element in their construction (a ball or a slide).



Figure 30: Parallel building without nudges.



Figure 31: Abstract creation of a castle.

4.2.3 Age Group (5-7 years)

For this age group, it was evident that they were extremely jumpy and very excited for the session. They instantly understood the task and started instantly. Interestingly, passerbys saw them and instantly wanted to join in.

1. What movements did the child controlling the 'robot' object make?

They used the object to mimic what the purpose of the construction and what it required. They tapped on shoulders, and gave certain pieces to the group. They used writing as a way of communicating. They would write instructions and have a back and forth on the paper. This age group used a lot of sound effects and humming sounds while communicating with each other. Some groups decided to construct animals, so they pointed at body parts to signify what piece corresponds to what part.

2. Was it easily understood by the other children while building? if not, did it become easier as the session went on?

The communication methods were not easily understood. Some groups were more successful than others to communicate. It did however, become easier as the session went on and they were forced to not talk.

3. Did the robot intervention help make the collaboration successful?

The robot intervention did help them collaborate, however, there were a lot of social dynamics that came into play. Group ideas were dominated by one person (leader) and the rest of them followed without being necessarily being satisfied with the idea. However, they have very short attention span, and don't really follow instructions too well. Hence, one key takeaway is that the robot needs to keep up their engagement level. They also constantly asked for feedback on their creations from me.

4. Was the final construction creative and coherent?

They kind of built something together but it wasn't really coherent. However, they did have really creative ideas but really struggled to execute it. Mostly,

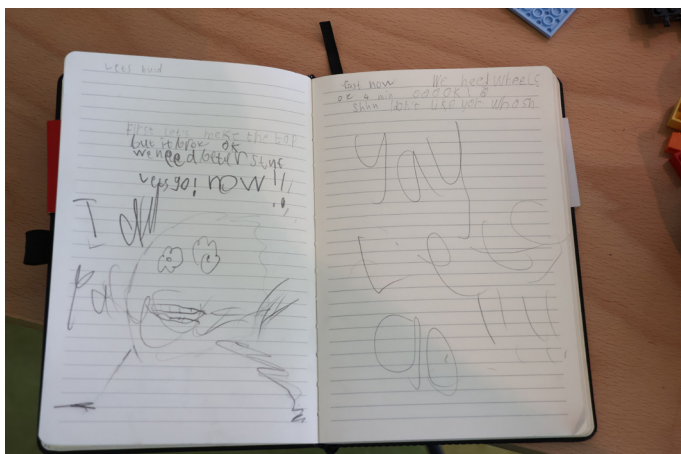
due to lack of knowledge of how to create it. Some children broke away from their group and just started making their own version because they were unwilling to compromise on their idea. They all were super competitive with each other and wanted to show off their individual skills.

5. What evidence of creativity stimulation occurred in the session?

They did build on each other's initial ideas of what to build but struggled to iterate on each other's concept too much. Their imaginations runs very wild when they are brainstorming what to do. However, they ruled out some concepts by claiming "they don't know how to build it". So they won't even try to build it or improvise. Most of the groups didn't want to attempt something outside their comfort zone.



Figures 33a & 33b: Communication by hand gestures (shushing & pointing)



Figures 32: Communication by writing on notebook



Figures 34: Creativity scaffolding by iterating on each other's ideas. In these images, they built multiple iterations of a spaceships together after they saw one person "leader" building it.

4.2.4 Age Group (8-11 years)

This age group had a really hard time to not use verbal communications and there was a lot of frustration amongst them. However, some groups were successfully able to complete this activity.

1. What movements did the child controlling the 'robot' object make?

This age group used a lot of facial expressions to communicate and very loud sounds of error or success. Drawing & writing on paper was very popular amongst groups to communicate the next steps for construction. They pointed at very specific blocks and were able to communicate where to place them. They had more concrete ideas and creations and less abstraction compared to other age groups.

2. Was it easily understood by the other children while building? if not, did it become easier as the session went on?

The actions were not easily understood by other children and it did not become easier as the session went on. They had a very difficult time completing this activity. Eventually, they got really frustrated and things got really chaotic.

3. Did the robot intervention help make the collaboration successful?

There was a lot of discussion before the start on what they wanted to build. Some groups came up with a way to communicate with each other using signs and written symbols. One group used the robot "controller" as a task delegator, which was assigning tasks for making a specific part of the construction and then integrating it together. Especially, with the structural integrity of the construction.

However, this age group mostly displayed very individualistic behaviour and almost a competitive behaviour for their own ideas. A lot of kids were unwilling to let go of their own idea, or compromise and decide what to do as a group. The robot controller was also tasked with searching for the right block in the pile.

4. Was the final construction creative and coherent?

The final construction was somewhat coherent, but

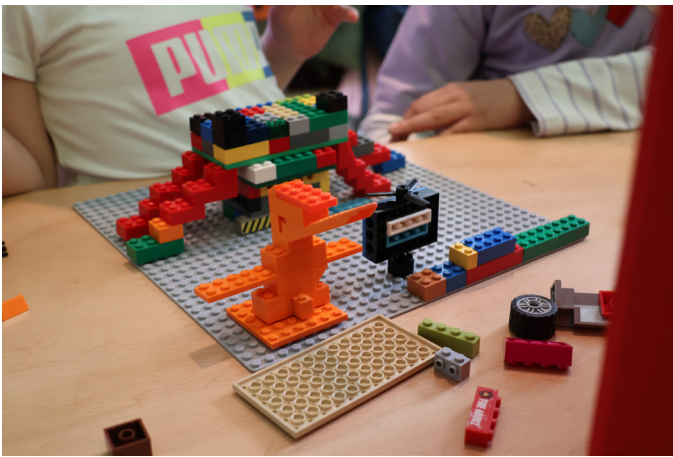


Figure 35: Coherent creation of a crab in its living room



Figure 36: Robot holder communicating by grabbing the piece which needs to be replaced.



Figure 37: Struggling to find the "right" piece in the pile of blocks.



Figure 38: Communicating via writing, while one person waits.

they didn't want to explore wild ideas. They didn't really play or undertook in many creative activities, so they were very slow to start. But after they started, it was impossible to end the session. Kids who were unfamiliar with LEGOs had a very hard time coming up with ideas about what to build. A general lack of wild ideas in all the groups, and a lot of self-imposed creative restriction (we'll only build something, if we have built it before")

5. What evidence of creativity stimulation occurred in the session?

They were all very slow to start building initially. They got stuck in deliberation and analysis mode. They needed a creative spark to do something. I had to give them a lot of nudges and spar with them to get them to build something. They did start scaffolding with each other's actions as the session went on. The major struggle was the inability to create something concrete and move away from abstract structures.



Figure 40: Onlooker behaviour, and a struggle to start building



Figure 41: Disputes regarding what to build and withholding of a piece to stop the construction.



Figure 39: Communicating with pointing and bringing pieces to the construction area.

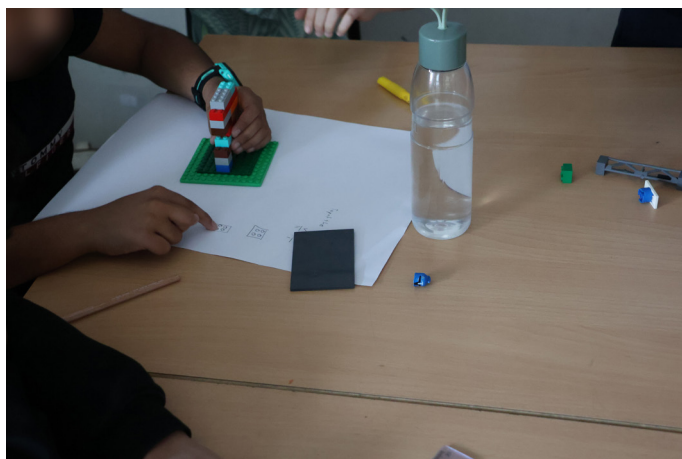


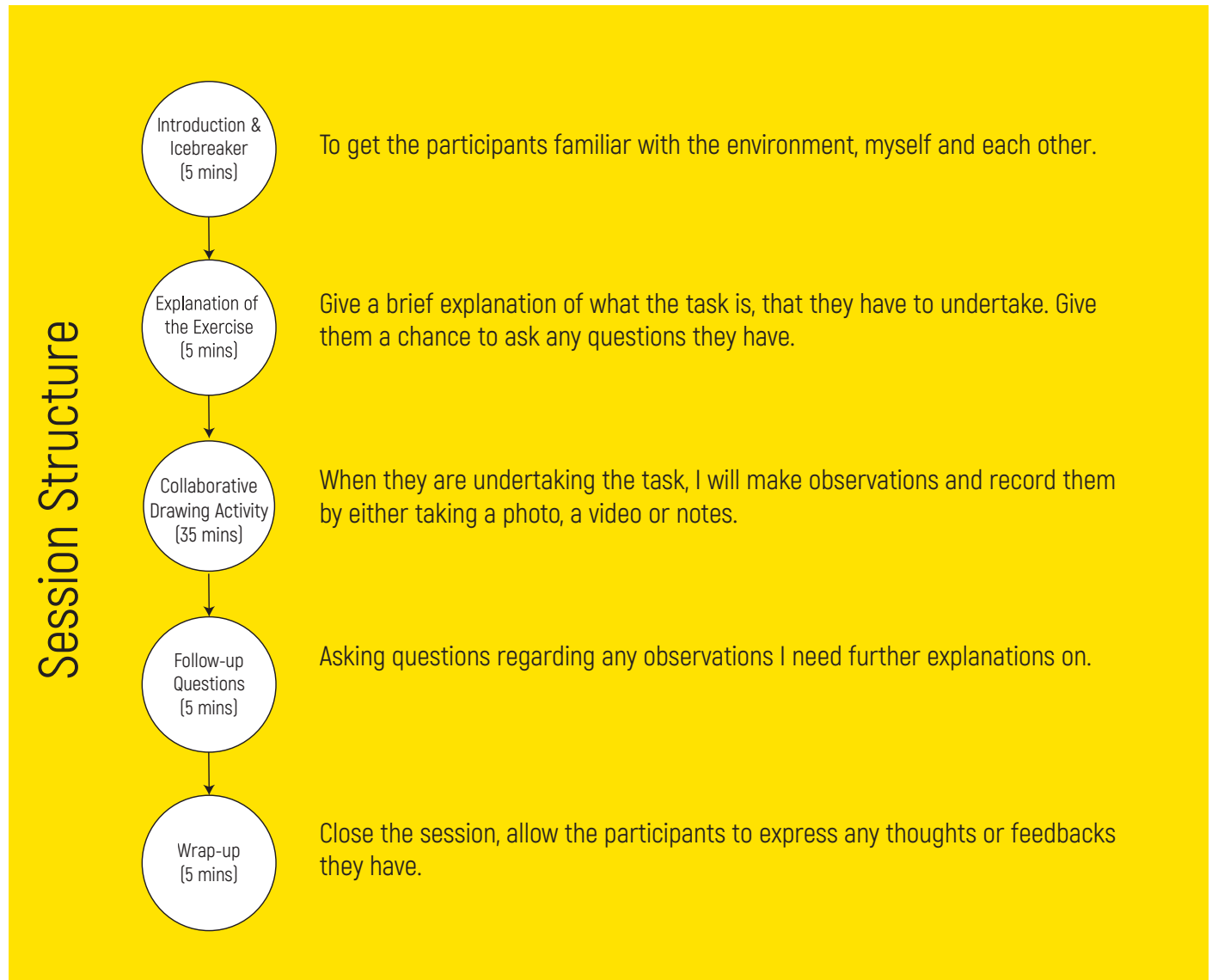
Figure 42: Communication by drawing out a step-by-step plan on paper.

4.3 Collaborative Drawing Session

RQ: How does facilitation of creative ideas occur in a collaborative-drawing session amongst kids?

Co-drawing session:

1. Have three children drawing on a single A3 paper.
2. There will be a co-drawing exercise amongst group of three children.
3. They will be asked to collaboratively come up with an artwork together.
4. The theme of the drawing will be to come up with "a toy buddy", that they would wish to be with them in this exercise.



Analysis of the workshop will be directed at answering the research question. The following observations will be recorded to get insights for design requirements of the robot.

1. How do their drawing actions influence each other?
2. Do they decide before or during the process how it is going to come together?
3. Do they adapt to each other's process to make it coherent or put no effort in integration?
4. How do they communicate with each other (assumption is they will just talk, but I will be on the lookout if there are other social cues they give each other)?
5. Did they have fun working together? Why or why not? Would they have worked better alone? What is their preference while drawing, working alone or working together?
6. What evidence of creativity stimulation occurred in the session?
7. How do above observations vary across age groups?

4.3.1 Thematic Analysis of Collaborative Drawing Session

The second activity of the workshops involved the Collaborative Drawing Session, which explored the children's creative collaborative dynamics and what role could a robot play in the context of human robot co-creation. The qualitative data collected during this activity was thematically analyzed based on the study's predetermined research and observation questions. The following subsections outline these findings, categorizing the design insights by age group to highlight the developmental differences and similarities in how users expect to communicate and interact with the social robot.

4.3.2 Age Group (2-4 years)

1. How do their drawing actions influence each other?

Most groups were unwilling to draw together, and straight up said no, when asked if they can make a drawing together. Imitation was very prevalent in this age group, they got inspired by what others drew and started drawing it. A lot of stuff they wanted to draw, but couldn't draw without seeing it. So they asked me to pull up the photos of different things so they could look at it and draw. Really happy to get inspired from each other.



Figure 43: Participant showing another how to draw a rocket

2. Do they decide before or during the process how it is going to come together?

After a while two groups started collaborating in each other's drawings as a result of nudges from my part. Once they started collaborating, they organically drew more things without need for nudges. They decided before starting, they were going to go step-by-step on a single sketch. One of them did the head, then the next did the body, then the next did the feet and so on.



Figure 44: Imitation through copying other's drawings

3. Do they adapt to each other's process to make it coherent or put no effort in integration?

It was very hard for them to adapt to each other's drawing process and they put in minimal effort into making a coherent drawing together. They would go off in their own individual directions while drawing.

4. How do they communicate with each other?

A lot of their communication was via their drawings on the paper, and pointing at the paper. They discussed their ideas of what to draw with each other and me.



Figure 45: When they got 'bored' of drawing they all started folding the papers, one after the other.

5. Did they have fun working together? Why or why not?
Would they have worked better alone? What is their preference while drawing, working alone or working together?

They did have a lot of fun with working in a group. It was a new experience for them to draw together. They were really happy to get inspired from each other, by looking at what other person's drawing and then adding some elements to their own drawings. But they would still rather prefer to draw alone on a single sheet. However, do enjoy to parallelly draw and collaborate with each other.

6. What evidence of creativity stimulation occurred in the session?

Biggest evidence of creativity stimulation, was them asking me for feedback for their drawings And a massive pride in telling me what they are drawing. However they would often say, "I want to draw so and so animal, can you show me an image, otherwise, I won't know how to make it." This could mean they are afraid to trust their own impulses, which leads to conformity over creativity.



Figure 47: A need to see what they want to draw, so they can copy.



Figure 48: Parallel drawing without any socializing.

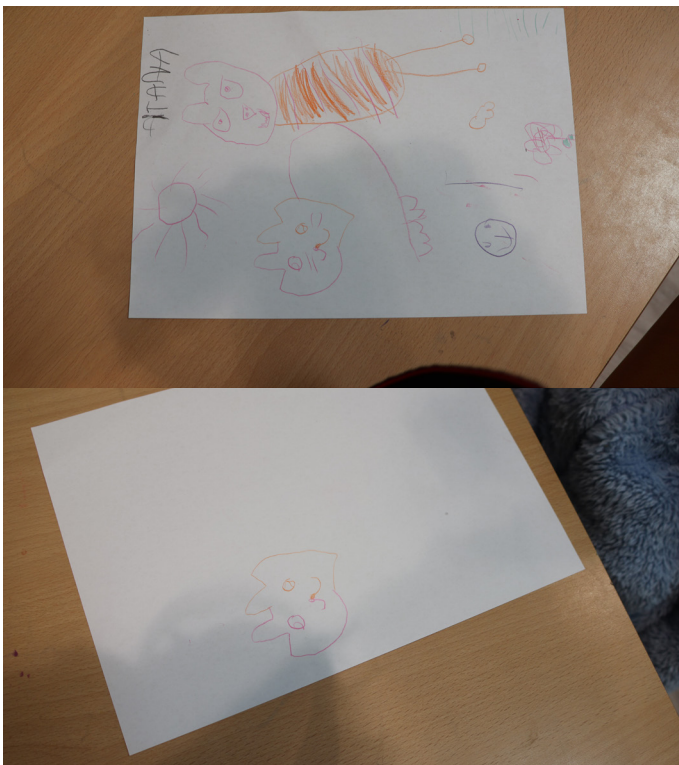


Figure 46: Rare successful drawing collaboration.



Figures 48a & 48b: Social behaviour exhibited through sharing of materials and offering different colored pencils to inspire.

4.3.3 Age Group (5-7 years)

1. How do their drawing actions influence each other?

They usually work alone, but were very willing to collaborate. They collaborated very organically drawing on top of the creations of their group mates. They get inspired by what their teammates draw and iterate on top of the drawing. There was no lack of creative ideas, some made multiple versions of their concepts, some iterated on one. The further they went into the exercise the more elaborate their sketches became.

2. Do they decide before or during the process how it is going to come together?

This age group is really about act first and think later. They just started drawing and improvised ways in which it could come together later. They initially struggled to coordinate but started enjoying the activity after figuring out the kinks of the process.

3. Do they adapt to each other's process to make it coherent or put no effort in integration?

They adapted well to make it coherent, and put in big effort into integrating the drawing into a coherent artifact.

4. How do they communicate with each other?

They used sound effects and role playing actions to communicate in the group. They would sometimes physically stop each other when drawing and show them how it should be drawn instead.



Figure 50: Completing the drawing after taking over from the previous person.

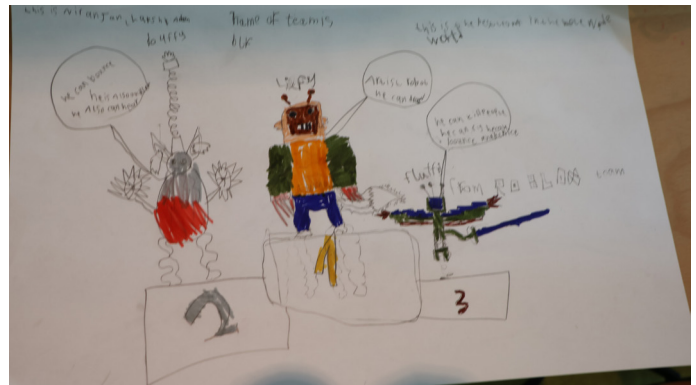


Figure 51: Completed collaborative drawing with three creatures, each being led by a different participant in the group.

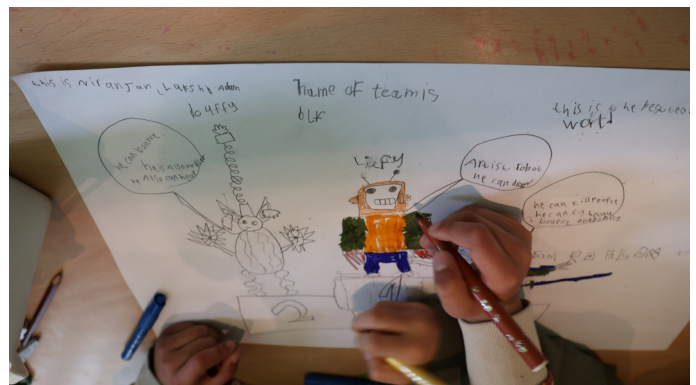


Figure 52: Big physical struggle while drawing together at the same time.



Figure 49: Turn by turn drawing collaboration.



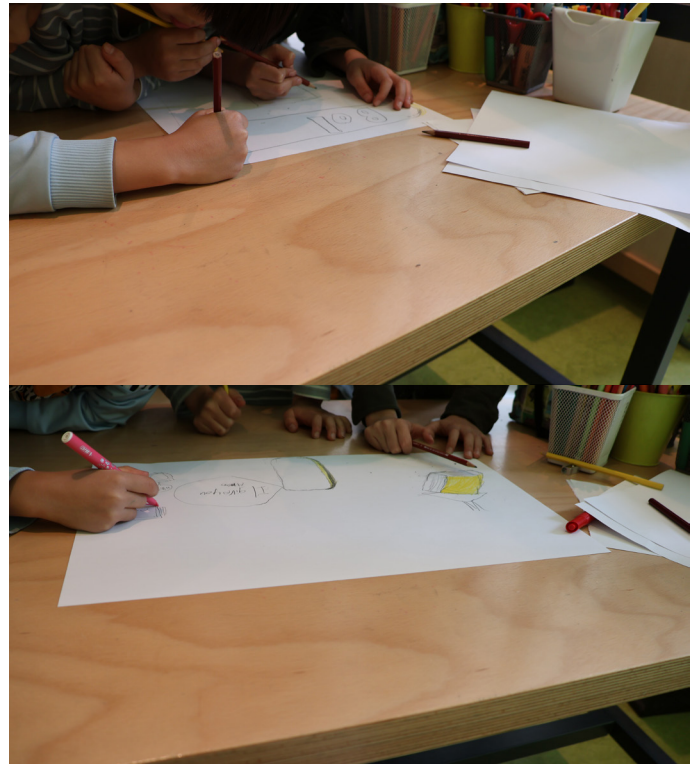
Figure 53: No time taken to plan or discuss, straight to action.

5. Did they have fun working together? Why or why not? Would they have worked better alone? What is their preference while drawing, working alone or working together?

This age group had the most fun working together and actually preferred collaborative drawing over drawing alone. This helped them bounce ideas off of each other and get help to draw something they didn't know how to draw.

6. What evidence of creativity stimulation occurred in the session?

Creativity stimulation occurred with them asking me, and each other questions about what to make. They expect nudges and feedbacks from other people. Me asking questions about their drawings really sparked a lot of ideas. They were constantly asking for spellings of certain things so they could label their drawings. They loved using colors in their drawings, and often combined sketching and coloring together, making it a simultaneous process.



Figures 55a & 55b: Creativity scaffolding by adding new colors to the drawing.

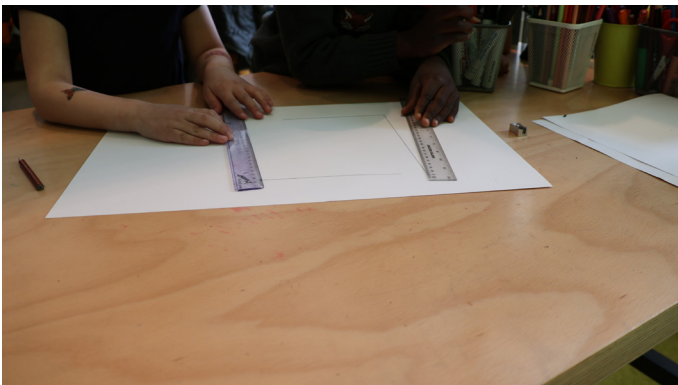


Figure 54: Use of rulers to make more accurate drawings.

4.3.4 Age Group (8-11 years)

For this age group, I asked them to draw a robot buddy together. So they could also inform what function should a social robot perform for them and how they pictured the limitations of the robot.

1. How do their drawing actions influence each other?

Most of the drawing actions was met with criticism from the rest of the group. There was much more erasing and re-sketching of drawings than in any other age groups. Sometimes the disputes led to massive discourse which often meant a complete stop in activity progression while they argued with each other what the next step should be. They had to be constantly reminded that there was a time limit to the task, in order to push them towards continuing it instead of just arguing.

2. Do they decide before or during the process how it is going to come together?

They had a small brainstorm and planning session before undertaking the activity. But however, some groups were able to execute the plan well, while others went off the rails at the first disagreement.



Figure 56: Struggling to draw together on one paper, one person draws while other shout instructions at them.

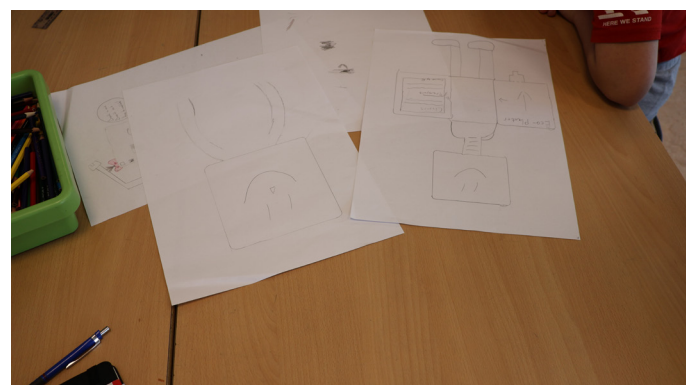


Figure 57: Some groups gave up on drawing together, and instead drew different drawings.

3. Do they adapt to each other's process to make it coherent or put no effort in integration?

Some groups did adapt to each other very well while other were unable to do this and unwilling to compromise to each other. They had refined ideas of the "toy buddy robot" they wanted.

4. How do they communicate with each other?

They mostly communicated verbally, used a lot of sound effects and exhales to display disappointment. Very hard for them to draw together on one paper. But their drawings of robot represented a lot of emotions which the robot should display.

5. Did they have fun working together? Why or why not? Would they have worked better alone? What is their preference while drawing, working alone or working together?

The overall feeling was they enjoyed participating in the activity and brainstorming ideas with each other but did not like working together. Especially, since they were not paired up with their friends.

6. What evidence of creativity stimulation occurred in the session?

They used humor as a way to stimulate creativity in their conceptual drawings of the robot. There was an inherent theme present in all the groups about the robot displaying multiple emotions. They asked questions to me about the limitations of a robot so they could pick and choose ideas. Some groups had a tight knit plan and just went about the business in a very mechanical way. There was a lot of iteration on ideas and concepts as the group was drawing.



Figure 58: One group had a plan beforehand and executed the drawing collaboration successfully.

Emerging Patterns

Going in the workshop, the research questions had already framed the specific aspects the sessions needed to probe. Because the data collected was qualitative and multimodal, that cannot be reduced to numbers, it had to be interpreted rather than simply recorded. The findings were therefore contextualised into a set of patterns through a reflexive analysis of the sessions, in which my own reading of what unfolded is treated as part of the interpretation rather than a neutral measurement. The map below aggregates these patterns and the connections drawn between them. The patterns are

clustered in two ways that matter for the project.

First, by the aspect observed, barriers to starting, the need for nudges and feedback, non-verbal communication, social hierarchies, inspiration between peers, and how age shapes the medium and the robot's role.

Second, by how each of these played out across the three age groups, highlighting where children's actions differed and where they aligned. This structure makes it possible to see not just what children do in a collaborative creative session, but how those behaviours shift with development.



4.4 Design Insights

2-4 Years

Preferred Collaborative Creative Medium: Collaborative drawing proved too difficult for this age group. Instead, **block construction** emerged as a more successful activity for fostering collaboration. Their creations across all mediums remain highly abstract.

Robot Social Behavior: The robot can be most effective when engaging in a **“back-and-forth” exchange of ideas** based on imitation and inspiration. It must provide **gentle, proactive nudges** to encourage children to share materials and collaborate.

Sustaining Engagement: To keep the children engaged, the robot should be capable of analyzing their abstract creations and **asking simple, open-ended questions** that spark further imaginative play.

Communication Modality: Children in this stage rely heavily on **sound effects and pictorial communication** to exchange ideas. The robot could utilize **expressive sounds and visual cues** (such as changing its appearance or providing a picture) as an alternative to complex verbal dialogue.

5-7 Years

Preferred Collaborative Creative Medium: A **drawing “co-bot”** is highly effective for this age-group. The children demonstrated **strong collaborative skills, actively implementing their artistic actions** on top of what their teammates had already drawn.

Communication & Interaction: Communication heavily involves **humming, sound effects, and physical pointing**. To interact naturally with this age group, the robot could feature a distinct auditory personality and possess either a physical or digital pointing mechanism.

Social Role: The robot should act as a **knowledgeable companion** capable of answering **basic questions** (e.g., spelling, number writing, simple math, or structural integrity advice). It should analyze their artifacts and suggest ways to make their **creations coherent and integrate ideas**.

Group Dynamics: The robot must actively manage group collaboration by **ensuring all opinions are considered**, preventing shy children from being overshadowed by

more dominant personalities. It should **constantly suggest new tasks** in the activity to keep them engaged.

Animism and Protection: An unexpected insight was the children’s belief that the **robot should be able to “protect itself and them.”** This aligns directly with Piaget’s theory of animistic thinking during the preoperational stage, where **children attribute lifelike vulnerabilities and protective roles to inanimate objects**.

8-11 Years

The Collaboration Gap: **Collaboration was the most difficult** in this older age group. Children struggled to be sensitive to each other’s ideas, highlighting **a significant need for a robotic facilitator**. When conflicts arose, they often defaulted to democratic votes or “rock-paper-scissors” to make decisions.

Robot Social Behaviour: Human intervention (my own) sometimes struggled to mediate group differences. A robot positioned as **a neutral, factual group judge** could effectively intervene to resolve arguments and guide consensus.

Overcoming the Obstacle to Start: Initiating a creative activity is the highest hurdle for this age group. The robot can provide immense value by **acting as an “inspirer” to spark those initial ideas**, kickstart the creative flow, and ultimately pull their attention away from digital screens.

Advanced Emotional & Humorous Personality: Because the children in this age group think more critically about a personal robot companion, they expect it to **display a complex range of emotional states** to convey its intentions. A **humorous personality is essential**, as much of this age group’s creative output is triggered by humor.

Practical Assistance: During block construction activities, **a robotic construction buddy could go beyond verbal suggestions and actively help find or provide the specific blocks** needed to achieve structural integrity.

5. Proof-of-Concept

5.1 Idea Generation

5.2 Concept Selection

5.3 Prototyping

5.1 Idea Generation

This section utilizes sketching of ideas and concept selection to translate the insights gained from Phase 1 into a working proof-of-concept. From the findings of the workshops and the interviews, there were the following three high level ideas that were developed to generate concepts that could work in this context: Social Robot Companion, Child Robot Co-Creation, Robot as Canvas.

5.1.1 Social Robot Companion

The first idea positions the robot as a companion that accompanies the child throughout a creative activity. Rather than producing artefacts of its own, its role is to sustain engagement and enthusiasm beyond what the child would maintain without the intervention, keeping them in the activity longer and drawing them back when their focus drifts. This responds directly to a recurring workshop finding: children needed to be questioned and conversed with during a task to keep their motivation high, and it is reinforced by the expert interviews, where teachers of both the 5–7 and 8–11 groups reported markedly short attention spans (≈ 20 –30 minutes). Just as importantly, the companion is envisioned as a facilitator of collaboration: the workshops surfaced strong group dynamics, natural leaders dominating the shared vision while quieter children receded, and frequent conflicts over ideas and materials. By questioning, prompting, and redirecting, the companion could help balance these dynamics – drawing out shy contributors, ensuring every voice is heard, and easing disputes so that a collaborative creative task keeps moving forward.

Collaborative Construction Buddy I

The collaborative construction buddy would be a multiple personality robot which could analyze the block construction while the child is working on it and suggest structural support needed to build on the construction, and in parallel what more could be added to continue this activity.

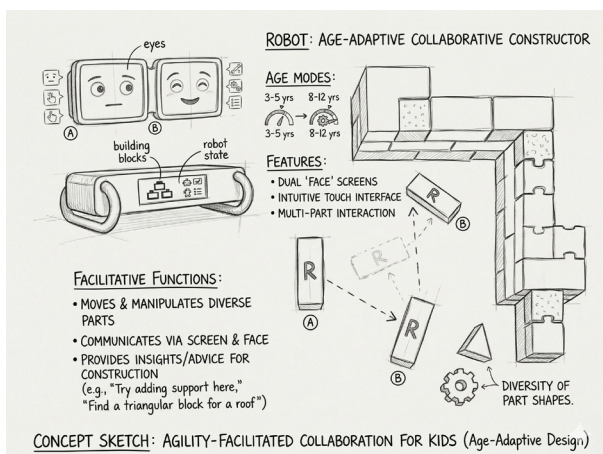


Figure 60: Collaborative Construction Buddy I

Collaborative Construction Buddy II

The version II, would have the robot physically participating in the construction with the entire group. It would identify the next blocks required and place them on the construction artefact. It would act as a mediator and a helper in a group construction activity.

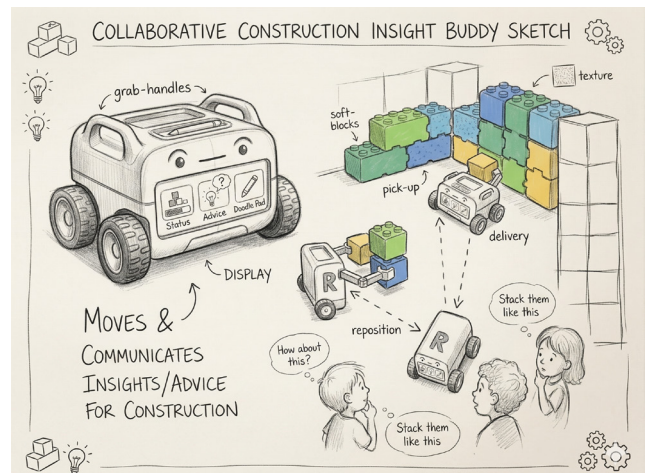


Figure 59: Collaborative Construction Buddy II

Multi-Robot Drawing System

In this concept, the system would be a multi-user setup in which each user has their own drawing robot on the table. Users can insert rough sketches to operate their respective robot, and the system analyses the global drawing produced so far to determine how each user's input should be rendered within their own section – all while keeping the overall composition cohesive and coherent. Here, the robot acts as a facilitator of ideas and an inclusive actor that takes everyone's voice into account.

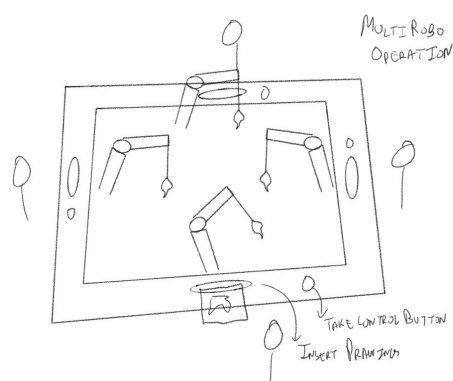


Figure 61: Multi-Robot Drawing System

Multiple Personality Robot

This co-buddy robot would have two distinct personalities: a happy, encouraging one and a highly critical one. For any creative activity, the robot would analyse the child's creation and offer both responses as suggestions, leaving it entirely up to the child how they choose to react to them.

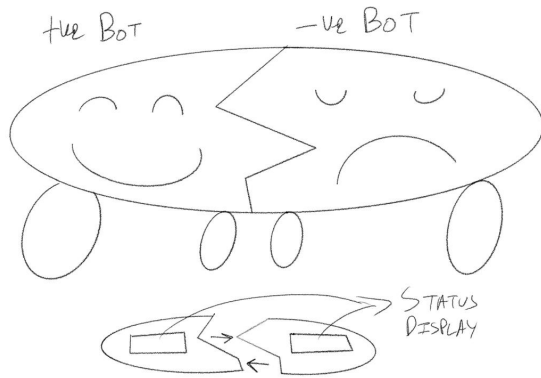


Figure 62: Multiple Personality Robot

5.1.2 Child Robot Co-Creation

The main foundation of this idea is the child robot "back-and-forth" workflow, where both the actors build on each other's actions. This would concentrate on one-to-one user interaction for proof-of-concept, and would focus more on how the actions of a robot can have an effect on the creativity and engagement of the children for the same creative activity. In the interviews with the teachers, there was a massive optimism about child-robot co-creation, which can be choreographed well together where both the actor's have an impact on the creations. Using the insights from the workshops, where the robot intervention was successful as a converser with the children and almost nudging them on with open ended questions and suggestions.

Clay Extruder Robot

A clay extruder robot would press more on the hands-on working with the material, where it can start with a design and then let the child interact with it and make changes accordingly.

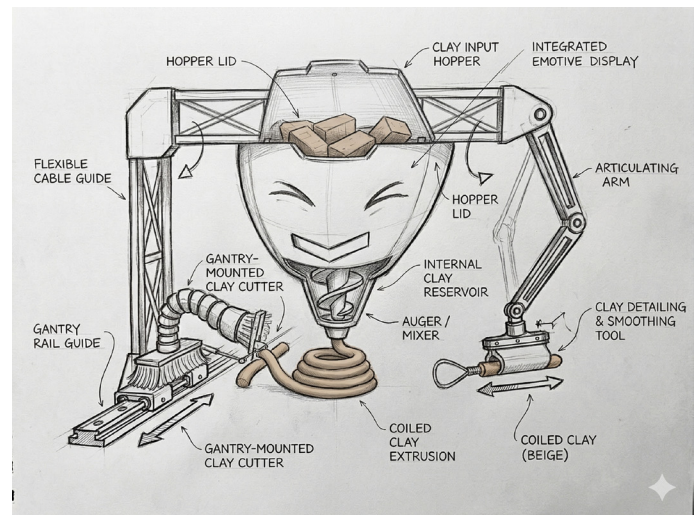


Figure 63: Clay Extruder Robot

Sand Raking Robot

This concept features a sand-raking robot that rakes the sand in response to the actions of the users interacting with it. It involves a multi-user interaction in which each user's action shapes the overall sand-art creation alongside the robot.

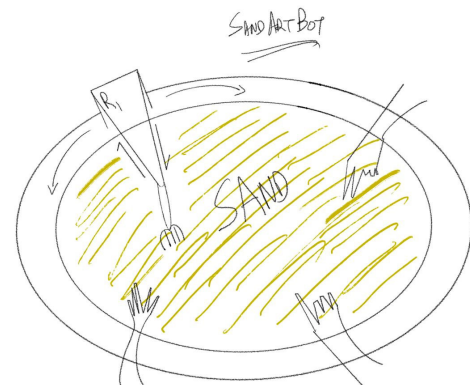


Figure 64: Sand Raking Robot

Expressive Projector Robot

This concept is an expressive robot with two personalities, similar to the Multiple Personality Robot, that conveys its suggestions by projecting them onto the child's drawing or construction. It expresses each persona through the movement of its two "eyes" as it interacts with the child.

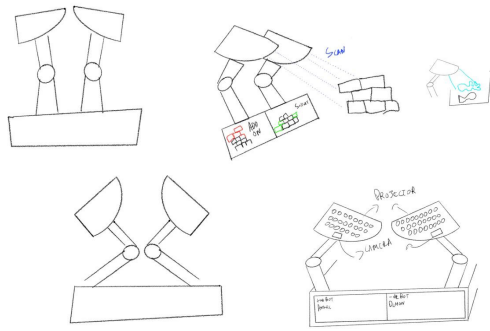


Figure 65: Expressive Projector Robot

Drawing Co-Bot

This concept features a collaborative drawing co-bot that physically draws on the paper alongside the child, following a choreographed workflow.



Figure 66: Drawing Co-Bot

5.1.3 Robot as Canvas

The third idea's fundamental ethos is to make the robot itself the canvas – dissolving the boundary between tool and surface so that the medium a child creates on is also an active participant in the activity. Rather than sitting beside the work or producing marks of its own, the creative surface becomes the robot: something that can change, react, and be explored. This reframes the creative act as a form of robotic art-making, in which the responsiveness and unpredictability of the canvas itself becomes a source of inspiration.

The direction was sparked by clear curiosity in the expert interviews, where the notion of a robot-as-canvas drew particular interest, and it builds on a shared developmental insight: teachers of both the youngest and oldest age groups observed that children enjoy and deeply engage with sensory-rich, hands-on activities.

The concept is further grounded in the explore-then-play sequence: a child's first interaction in any creative task is with the canvas itself, examining its properties before play can begin. By making that surface responsive and explorable and inviting the child to discover what it af-

fords rather than presenting a blank, passive sheet. The concept aims to lower the barrier to starting, a notable hurdle for the oldest group, and to provoke open-ended experimentation that yields unexpected, emergent creations.

Mouldable Robot

The mouldable robot would have multiple users interacting with it, its body acting as the canvas. The users' physical actions – twisting, pinching, pushing, and pulling – would shape the entire surface, fostering successful collaboration.

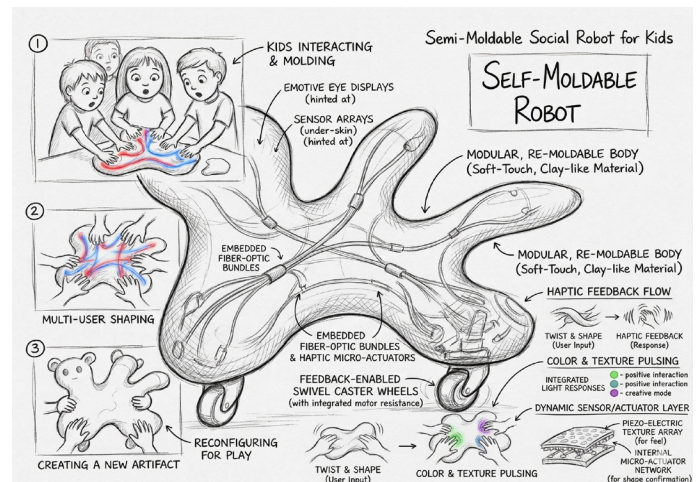


Figure 67: Mouldable Robot

LED Light Table Robot

The LED light-table robot would interpret the users' physical actions to change the luminosity, colour, and pattern of its lights, making for an engaging, hands-on, multi-user interaction.

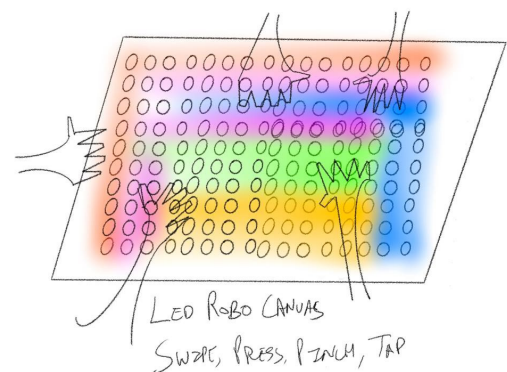


Figure 68: LED Light Table Robot

Multi Robot Display Canvas

In this concept, multiple robots move across a display and change it beneath them with colours and varied patterns. It is a multi-user interaction in which the users' physical actions influence the path of each robot, producing unexpected creations and fostering successful collaboration.

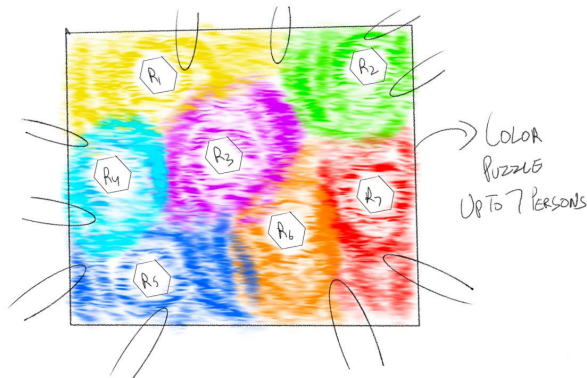


Figure 69: Multiple Robot Display Canvas

Holographic Construction Robot

This concept features a robot that takes in a 2D drawing, scans and analyses it, and then generates a holographic 3D construction blueprint that can be built using blocks. The users can then begin placing the blocks to create a physical, three-dimensional representation of their drawing.

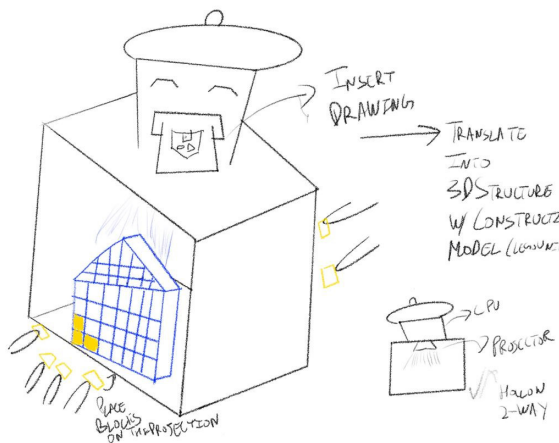


Figure 70: Holographic Construction Robot

Projector Art Platform

This concept features a tabletop device that casts light projections to create a form of light art. Users interact through hand movements made between the projector and the displayed art: the device translates these shadow movements into responsive actions that change the patterns on display. By supporting multiple users' actions and interactions at once, the concept aims to keep children engaged.

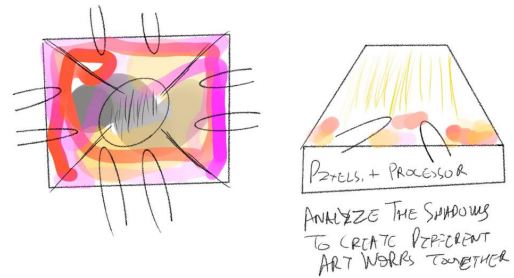


Figure 71: Projector Art Platform

Dancing Robot

This concept features a robot in a box that "dances" in response to the users' hand gestures. It works on a turn-by-turn basis: the robot turns to each user to register a move, records their hand gestures, and translates them into a movement. It then turns to the next user, interprets their gestures, and layers that movement on top of the previous ones.

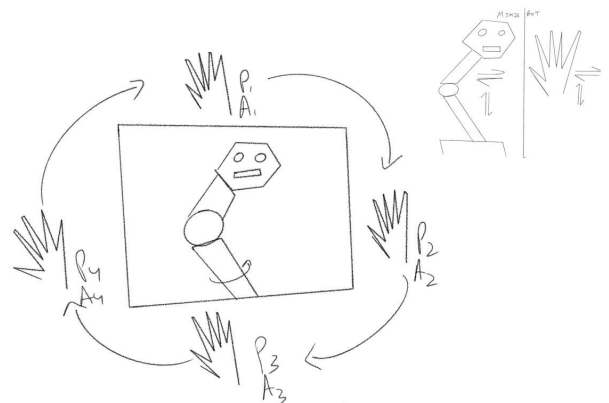


Figure 72: Dancing Robot

5.2 Concept Selection

5.2.1 Harris Profile

To evaluate the concepts, the Harris Profile tool (Van Boeijen et al., 2013) was used first. It scores each concept against multiple criteria and produces a numerical score for each. The criteria were selected from the design requirements and the insights uncovered during the workshops and the teacher interviews. The following criteria were chosen:

1. Co-Creation Loop

The concept should enable a continuous “back-and-forth” exchange, in which the child and the robot build on one another’s actions. This stems from the finding that children disengage or let the robot do the work unless the activity demands their sustained, active participation.

2. Creativity Facilitation

The concept should actively spark and scaffold the child’s creative output through nudges, suggestions, and new directions, rather than simply entertain. This reflects the repeated observation that children rely on nudges and feedback to keep going, and that older children in particular need help overcoming the “analysis paralysis” that stalls them at the start.

3. Age-Adaptiveness

The concept should be able to adapt its behaviour and complexity across the three developmental brackets (2–4, 5–7, 8–11), the central aim of the project given the distinct cognitive and social needs of each group.

4. Child Agency

The child should remain the main author of the creation; the robot should suggest and support without imposing or taking over. This follows directly from the need to nudge children without overriding their free will, especially for the youngest group.

5. Expressiveness & Engagement

The concept should convey its intent through clear, non-verbal and expressive cues, and hold the attention of children with notably short attention spans. This draws on the requirement for legible non-verbal communication and the older group’s expectation that the robot display a range of emotion and humour.

6. Group Collaboration

The concept’s potential to facilitate collaboration among multiple children – drawing out quieter contributors, balancing dominant personalities, and easing conflict – addressing the strong group dynamics surfaced in the workshops.

7. Feasibility (within scope)

The concept must be realistically buildable and testable within the time, budget, and technical constraints of the project, a practical requirement of the Research-through-Design approach.

Harris Profile

Each bar scores a concept against a criterion on a -- / - / + / ++ scale. Blue (right) = strength, red (left) = weakness.



Figure 73: Harris Profile

From the Harris Profile, the 'Expressive Projector Robot' received the highest score (+9). It scored positively on almost every criterion: it enacts the back-and-forth co-creation loop by projecting suggestions that the child can respond to; it facilitates creativity through personality-driven nudges; it preserves the child's agency, since the suggestions are cast onto the child's own paper and it remains entirely up to the child which of them to act on; and it communicates expressively through the movement of its two animated "eyes." Its only weakness was group collaboration – an expected result, as the concept is deliberately one-to-one, which is precisely the dimension scoped out of this proof-of-concept.

The 'Multiple Personality Robot' followed as a close second (+7). It shares the same underlying mechanic – analysing the child's creation and offering two contrasting responses, an encouraging one and a critical one, as suggestions the child is free to accept or ignore. It scored slightly lower mainly because it lacked the expressive, embodied presence of the projector robot. At the other end of the scale, the 'Multi-Robot Display Canvas' scored lowest (-1), held back chiefly by its limited creative facilitation and lower feasibility within the scope of the project.

Rather than treating these two leading concepts as competing alternatives, they were recognised as comple-

mentary. The Multiple Personality Robot contributes the suggestion mechanism, a set of distinct creative "lenses" the child can choose between, while the Expressive Projector Robot contributes the means of delivery, projecting those suggestions directly onto the child's drawing and embodying each persona through the movement of its eyes. The directions of the two highest-scoring concepts were therefore combined and carried forward for the prototyping the proof-of-concept.

5.2.2 Synthesising Findings into Conceptualisation

The requirements identified through the expert interviews and the insights from the co-design workshops were consolidated into five guiding requirements for the prototype. In doing so, two shifts were made deliberately. First, the requirement for multi-user interaction and conflict mitigation was set aside for this proof-of-concept, which focuses on a one-to-one interaction before group collaboration is taken on at a later stage. Second, two qualities that had run implicitly through the earlier findings – the child's authorship of the work, and the active facilitation of creativity – were made explicit as requirements in their own right. This produced the following five synthesised requirements, which turned into the vision for designing the prototype and an intervention that could satisfy the derived findings: Tactile & Sensory-Rich Hardware, a Co-Creative "Back-and-Forth," Child Agency, Creativity Facilitation, and Age-Adaptiveness.

Tactile & Sensory Rich Hardware

For taking the concepts selected further, there were the following synthesised requirements which turned into the vision for designing the prototype and providing an intervention that could satisfy the derived findings. To start off, one key design finding was creating a prototype that could provide a tactile & sensory rich hardware for a more immersive experience. This was evident in the co-creative workshops and interviews, this would help the children to be more engaged with the product. Here, the expressive projector robot concept stood out in terms of feasibility and immersive ability, such that it could provide a physical expression on the paper to draw as a companion with the child.

Co-Creative Back & Forth

To satisfy the vision of the conceptualisation, the prototype should have a co-creative back and forth with the user. This is one of the core motivations for the project to explore how the human robot collaboration can occur in creative spaces. This would require both the agents undertaking a proactive role in the task rather than master and assistant which is the usual case with the emerging technologies in the domain of AI and robots. Here a combination of both the concepts of expressive projection robot and the multiple persona robot fit in perfectly. With the projector concept acting as a collaborator during drawing and the multiple personas giving the child an active decision to make during creations. It would create a loop where the child and the system would act on each other's ideas, and develop the cre-

ations further and create a back and forth communication with each other without verbally communicating rather expressing themselves through actions or suggestions during the process.

Child Agency

This leads into the requirement of Child Authority during the creative task, there is a fine balance needed in the co-creation cycle so that the system doesn't take over the task yet remains an active co-creator. That's where having the feature multiple personas fits very well, as it can portray the system as having contradiction within itself. So, it doesn't specifically 'command' the child to take a certain direction. But provides the child with a choice which direction they would prefer to go at that stage. By giving them the ability to use the system as a scaffolder rather than a commander, there is big potential in the multiple persona model to give meaningful suggestions to the child while the child retains the authorship of the creations.

Creativity Facilitation

At the heart of the vision is the requirement that the prototype should actively facilitate the child's creativity, rather than simply give them a tool to draw with. This was one of the clearest threads across the literature, interviews, and workshops: children hold a genuine capacity for imaginative, divergent thinking, but they often self-censor and retreat to what is familiar, and the older ones in particular tend to freeze at the start of a task, needing a spark to push past their "analysis paralysis." What emerged was that creativity here has to be invited, not merely permitted. This is where the pairing of the expressive projection robot and the multiple persona robot fits the requirement. The analysis-and-suggestion pipeline reads the child's own drawing and offers grounded, projected nudges directly in their creative space on the paper, keeping every suggestion contextual and actionable. So the system could spark divergent, unexpected ideas as readily as it can help ground them. In this way the concepts scaffolds the child to explore beyond the familiar and transform ideas in their own way, satisfying the process-based view of creativity while the child remains the author of the work.

Age-Adaptiveness

A central pillar of the project, and the requirement that most shaped the vision, is that the system must adapt its behaviour across different age groups. The exploration

phase made clear that this is not a later refinement but a first-order design variable: cognitive, social, and creative behaviours shift markedly across the three brackets – the youngest work concretely and rely on imitation and motor grounding, the middle group engage playfully and socially and need constant novelty, and the eldest draw deliberately and self-directedly and seek complexity. Crucially, the collaborative role the children expect of a robot shifts with them too, from an authority to follow, to a playful partner, to a facilitator to be negotiated with. A single, fixed interaction could therefore never serve all of them. Once again the combination of the two concepts

answers this well. The AI system drawing analysis is capable to infer the child's developmental stage from their drawing and calibrate the suggestions accordingly – simpler, single-object nudges for the youngest, and richer, more detailed and realistic ones for the older children – while the multiple persona concept lets the system adjust its tone, its humour, and the kind of creative move it offers to suit each age. Together, the projection and persona system can meet each child where they are, scaffolding the creative task at a level that fits their stage rather than imposing one mode on everyone.

Synthesising the Findings into the Proof of Concept

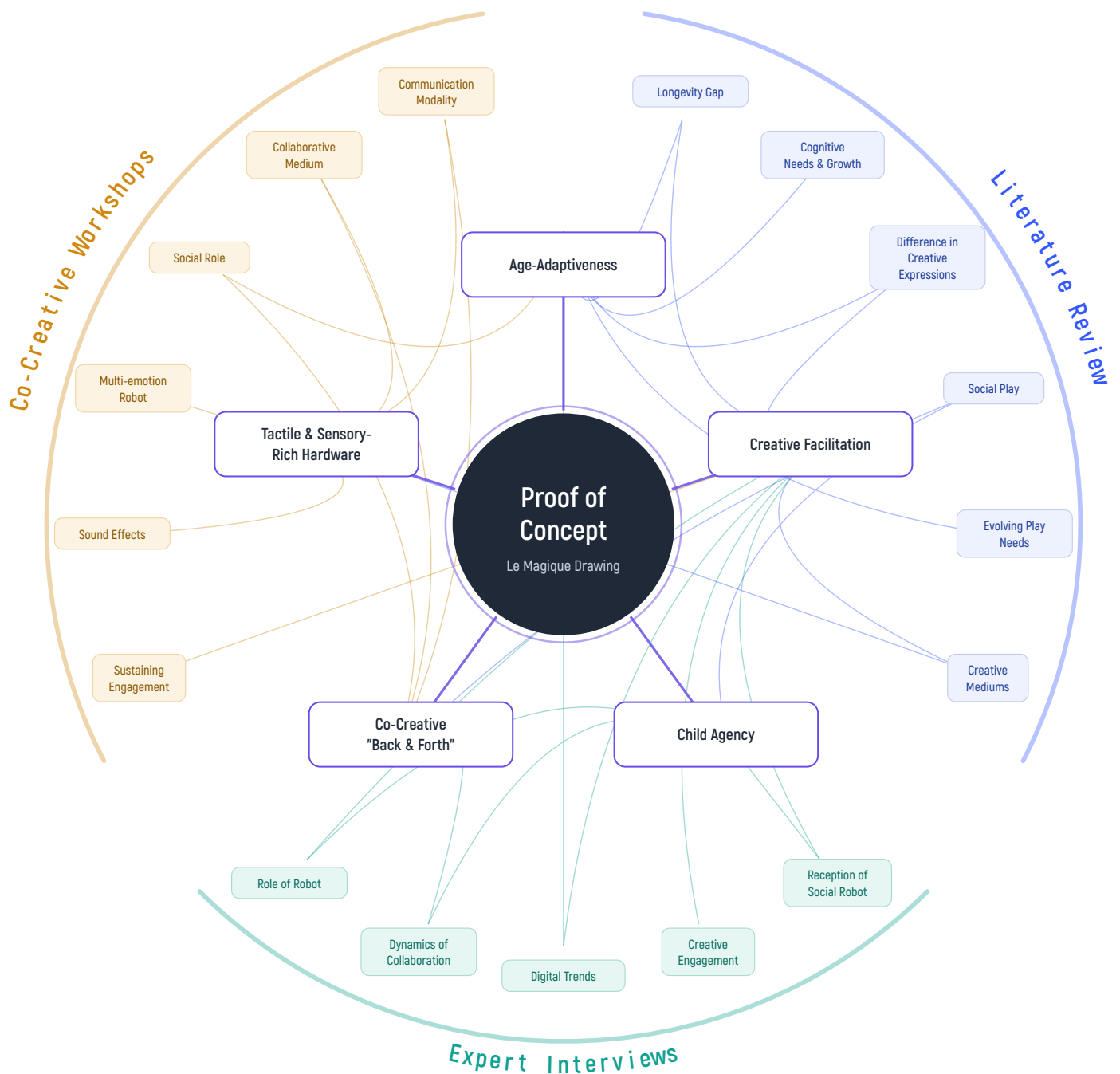


Figure 74: Synthesising findings from Phase 1 into a proof-of-concept.

5.3 Prototyping

From the first phase of understanding the user, it became clear that the intervention needed to foster a healthier relationship between digital technology and children. This meant changing the way such technologies are perceived: rather than being used as a means to an end, the system was intended to establish a co-creative, back-and-forth loop in which the child and the embodied AI act as proactive collaborators. Because the interaction had to suit children of very different ages, it was also necessary to design a workflow that could adapt to each age group and provide developmentally appropriate responses.

Several aspects drawn from the earlier insights were central to this intention. The child had to retain authorship of the work, while the system acted as a creative facilitator of ideas – helping the child in their artistic expression while sustaining a high level of engagement. The system also had to entertain, maintaining a humorous quality by adopting distinct personalities. To ground the interaction in the physical world, the plan was to use a projector to cast the AI's suggestions directly onto the child's page. This would let the children perceive the effect of the AI on the paper itself, making its presence feel more real – an active collaborator working alongside them.

The development itself was approached iteratively and in two stages: a digital prototype, followed by a physical embodiment. The first, digital prototyping, covers the software that analyses the children's drawings and returns active nudges: large language models (LLMs) and vision-language models (VLMs) read each drawing and generate suggestions, forming the co-creation loop. Here, the approach was to build, test, and iterate repeatedly, refining the prototype until it reached a level suitable for testing with actual users. The second, physical embodiment, integrates a projector and a camera for live capture and feedback, together with an expressive robot – the physical presence through which the system interacts with the child.

Within this project, however, the two stages were taken to different depths. The digital prototype and its projection setup – the analysis-and-suggestion pipeline, the projector, and the camera – were fully built and carried into testing with children. The expressive robot, by contrast, remained a design vision: it was developed as a concept and is presented through renders, but was not physically constructed or included in the evaluation. Throughout this chapter, then, the “system” the child interacts with refers to the projection-based pipeline,

with the embodied robot as the intended next step rather than a tested artefact.

5.3.1 Digital Prototyping

5.3.1.1 Analysis of Drawings

The analysis stage transforms a single image of a child's drawing into a structured, machine-readable understanding of it. The captured image is passed to

The analysis stage transforms a single image of a child's drawing into a structured, machine-readable understanding of it. The captured image is passed to a vision-language model (VLM), Gemini 2.5 Flash, which can interpret the loose, abstract, and non-photographic marks typical of children's art – recognising that a brown scribble is a tree, or that a circle with two dots is a face – in a way that conventional, rule-based computer vision cannot.

Rather than being asked an open question, the model is guided by a structured system prompt that frames it as a creative collaborator grounded in child-development theory (Piaget, Vygotsky, Erikson, and Montessori) and instructs it to reason in developmental terms and to respond only in a fixed format. It returns a single record describing the drawing across several dimensions: an inferred developmental read (the age bracket and stage), the content (objects present, conspicuously missing elements, spatial layout, and level of detail), the theme and narrative, the affective tone (mood and energy), the colour palette, and an assessment of creativity scored against the TCT-DP factors. Crucially, this analysis is internal, the child never sees it, and because it is structured rather than free text, it forms a single, consistent foundation that every later stage of the system reads from.

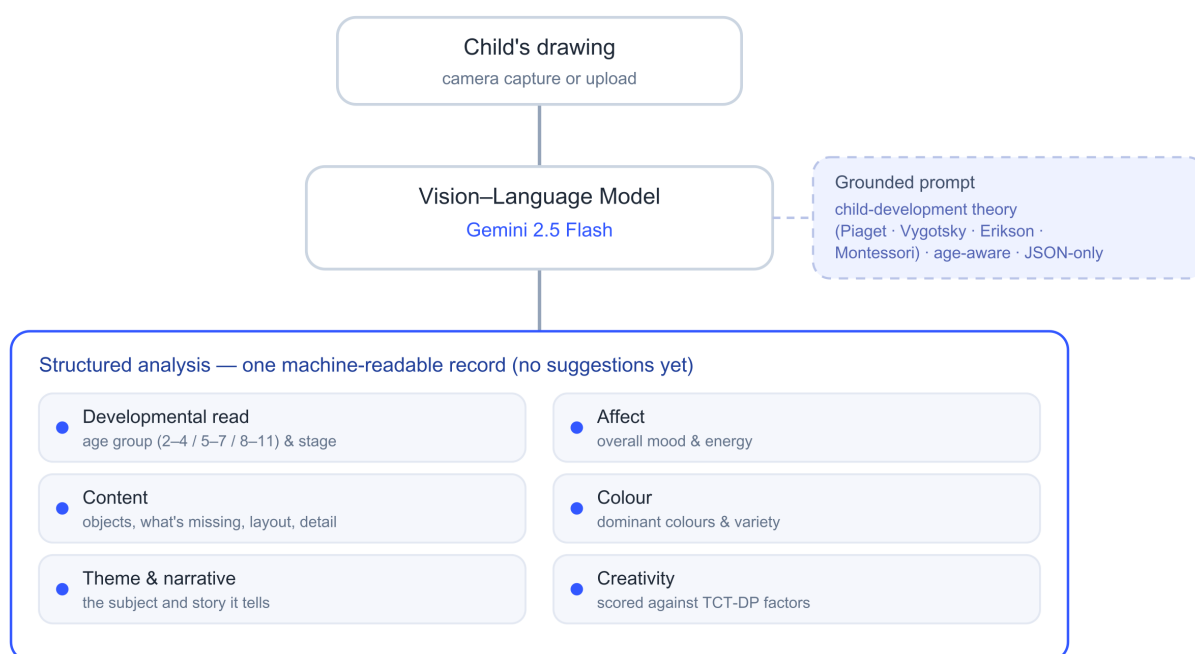
Since, Gemini 2.5 Flash is a general-purpose foundation model, the analysis was not retrained at the level of model weights; instead, it was developed, calibrated, and validated against the KIDO (Kids' Drawing) dataset (Çiftçi et al., 2025) – a dataset of real children's drawings labelled by age, gender, and emotion. KIDO served two purposes.

First, it provided a ground-truth benchmark: running the pipeline across a sample of KIDO drawings made it possible to check whether the model's inferred age bracket and emotional reading aligned with the dataset's

labels, and to surface systematic failures – for example, suggestions that were too complex for the youngest group.

Second, it drove an iterative prompt-refinement loop: after each batch, the quality and age-appropriateness of the analysis were rated, and these ratings were compiled into a persistent context file that is prepended to the system prompt on every subsequent run. In effect, the model was progressively tuned through structured, in-context feedback grounded in real children's drawings – improving the consistency and developmental appropriateness of the analysis without modifying the underlying model.

Drawing Analysis — building a structured understanding



This structured understanding becomes the input to the suggestion stage (next section).

Internal — the child never sees the analysis itself.

Models — analysis: Gemini 2.5 Flash (vision-language). Suggestion generation (next section): Gemini 3.1 Flash Image.

Figure 75: Image analysis logic flow chart

Version 1 - Analysis Dashboard

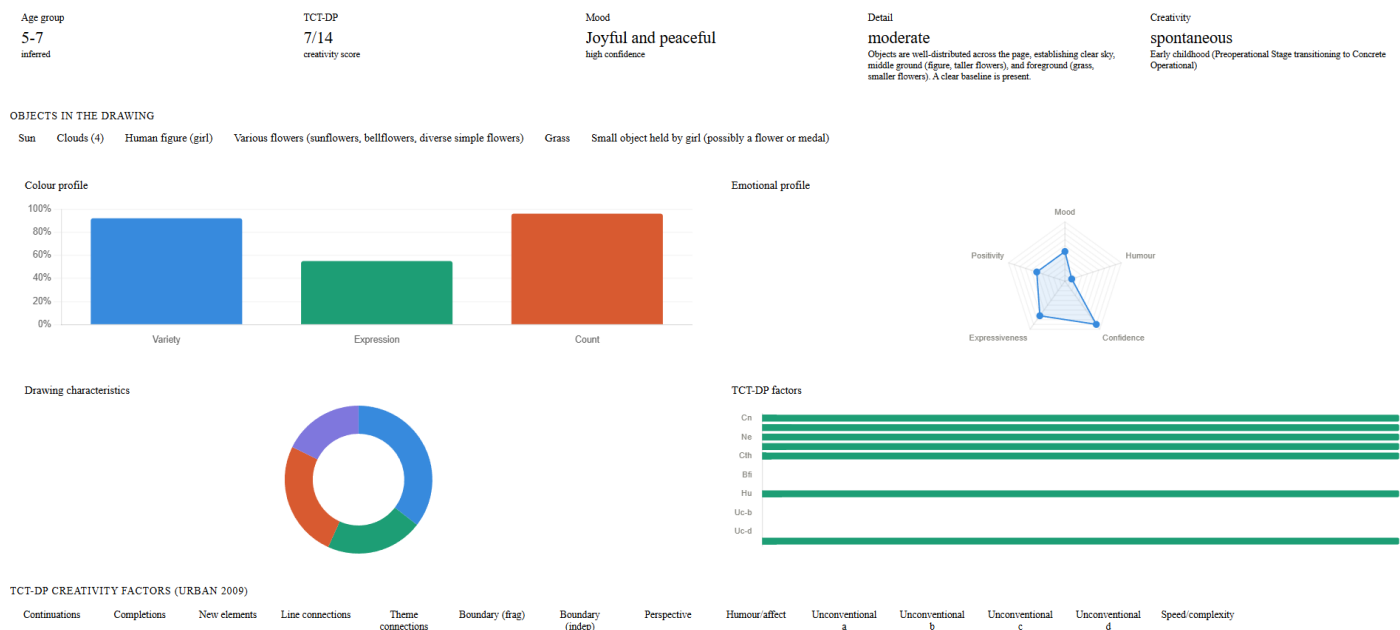


Figure 76: Analysis dashboard v1

Focus: can the AI read a drawing?

The first prototype was a diagnostic instrument rather than a designed workflow. Its sole purpose was to establish the premise on which the entire concept depended: could a vision-language model meaningfully interpret a child's drawing? Built on the Gemini API and presented as a simple web dashboard, it took a single uploaded drawing and returned a structured "read" of it – a TCT-DP creativity score (assessing the drawing against the factors of the Test for Creative Thinking–Drawing Production), a developmental-context estimate of the child's age and stage, and an emotional profile capturing the drawing's mood and energy.

This version was deliberately narrow. Before investing in any interaction design, it was essential to know whether the model could perceive a child's work with enough nuance to act on it later. Displaying the drawing alongside its machine-readable analysis made the model's interpretation legible and testable at a glance.

The dashboard confirmed that the model could indeed assess a drawing's creativity and developmental stage to a useful degree. Its limitation, however, defined the next step: it only observed the child. It produced a rich description but offered nothing for the child to act upon – it was an assessment tool, not a collaborator.

Version 2 - (+ Good Cop/Bad Cop)

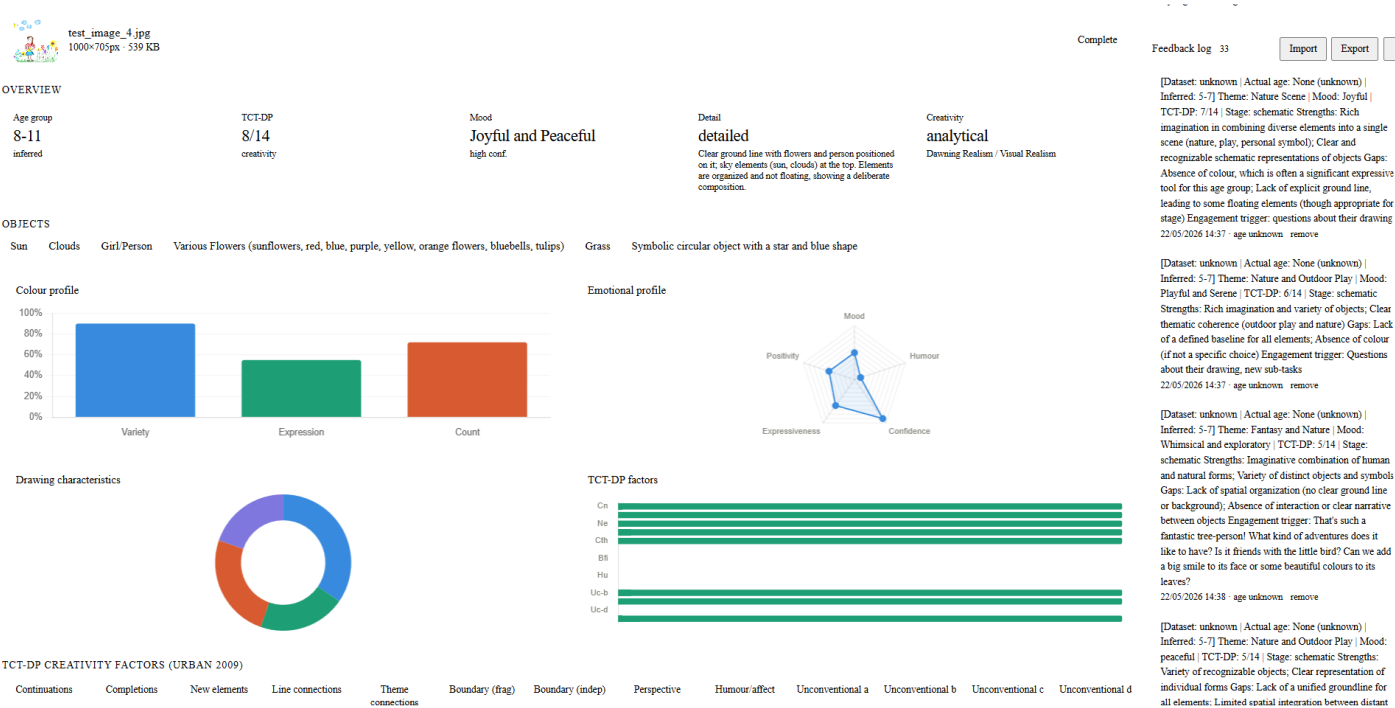


Figure 77: Analysis dashboard v2

Focus: make it actionable

The second version layered the core co-creation mechanic on top of the analysis: a two-personality suggestion nudges. The Good Cop (Optimist) proposed additions – new elements the child could add to extend their drawing – while the Bad Cop (Realist) proposed improvements – things to complete or make more believable. For the first time, the system did not merely describe a drawing but responded to it with concrete, drawable proposals.

The choice of two opposing personas was a deliberate design decision rather than a technical one. A single authoritative voice risks the child simply obeying the machine; by offering two contrasting perspectives, the system invites the child to weigh, choose, and reject – preserving their authorship of the work. This directly served the project's guiding requirement that the child, not the robot, remain the author of the artefact.

This turned the diagnostic dashboard into a genuine suggestion tool. Its weakness was that the suggestions, generated from the analysis alone, were still generic: the model would propose plausible but unspecific additions that did not always relate to what the child had actually drawn.

Version 3 - (+ Object Identification)

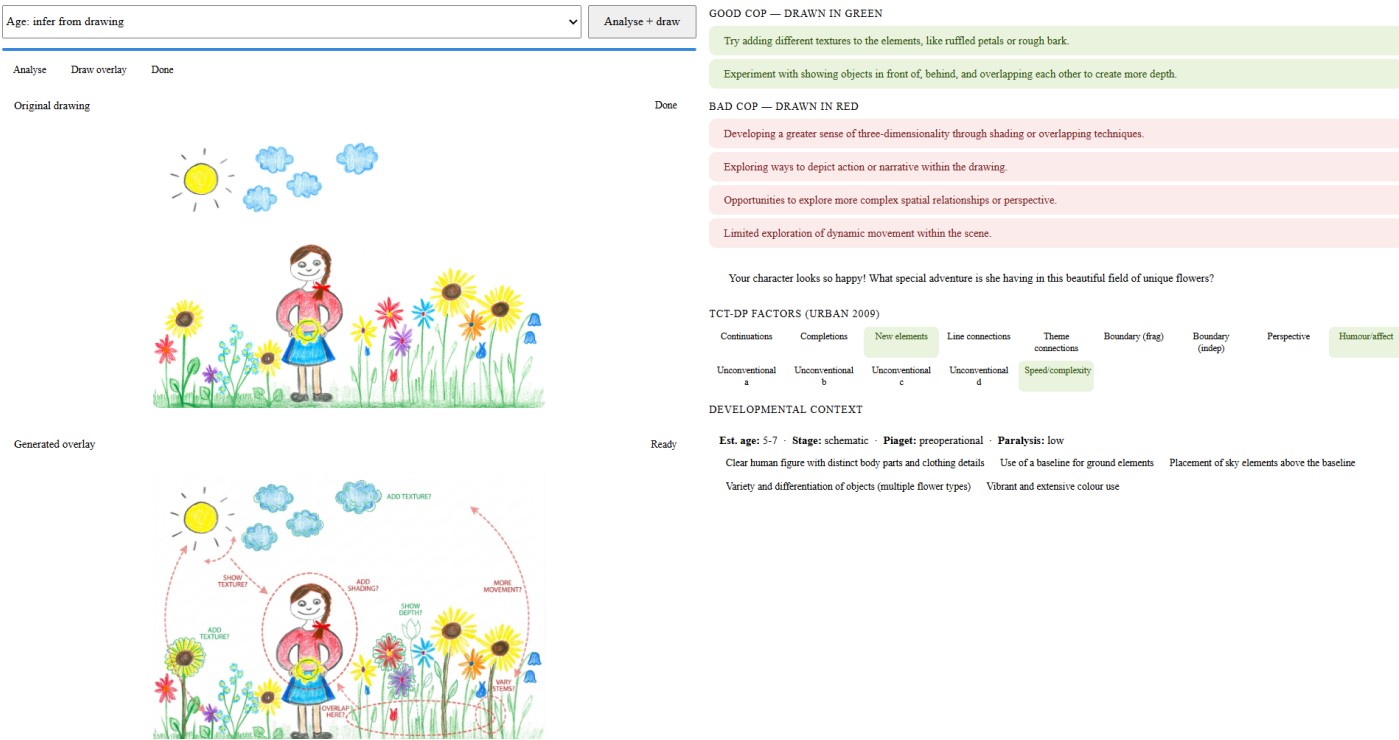


Figure 78: Analysis dashboard v3

Focus: ground the suggestions

The third version addressed that weakness by adding explicit identification of the objects present in the drawing and feeding this back into the suggestion process. Rather than proposing a generic “cloud” or “sun” for any scene, the system now named what was actually on the page and tailored its suggestions to it – a trunk beneath the specific tree the child had drawn, a door on the house they had sketched.

This grounding step is where the suggestion quality matured. Because the underlying model could not be fine-tuned directly, its output was steered through a human-in-the-loop feedback process and reference material, reducing hallucination and anchoring each suggestion in the child’s own work. Naming the drawn objects gave the personas something concrete and specific to build upon, making their proposals feel relevant to this child’s drawing rather than to drawings in general.

The result was context-aware suggestions. Yet the system remained a one-off tool: the interaction was still a discrete cycle of upload -> analyse -> suggest, with no sense of an ongoing, evolving session.

Version 4 - (Persistent Live Use)

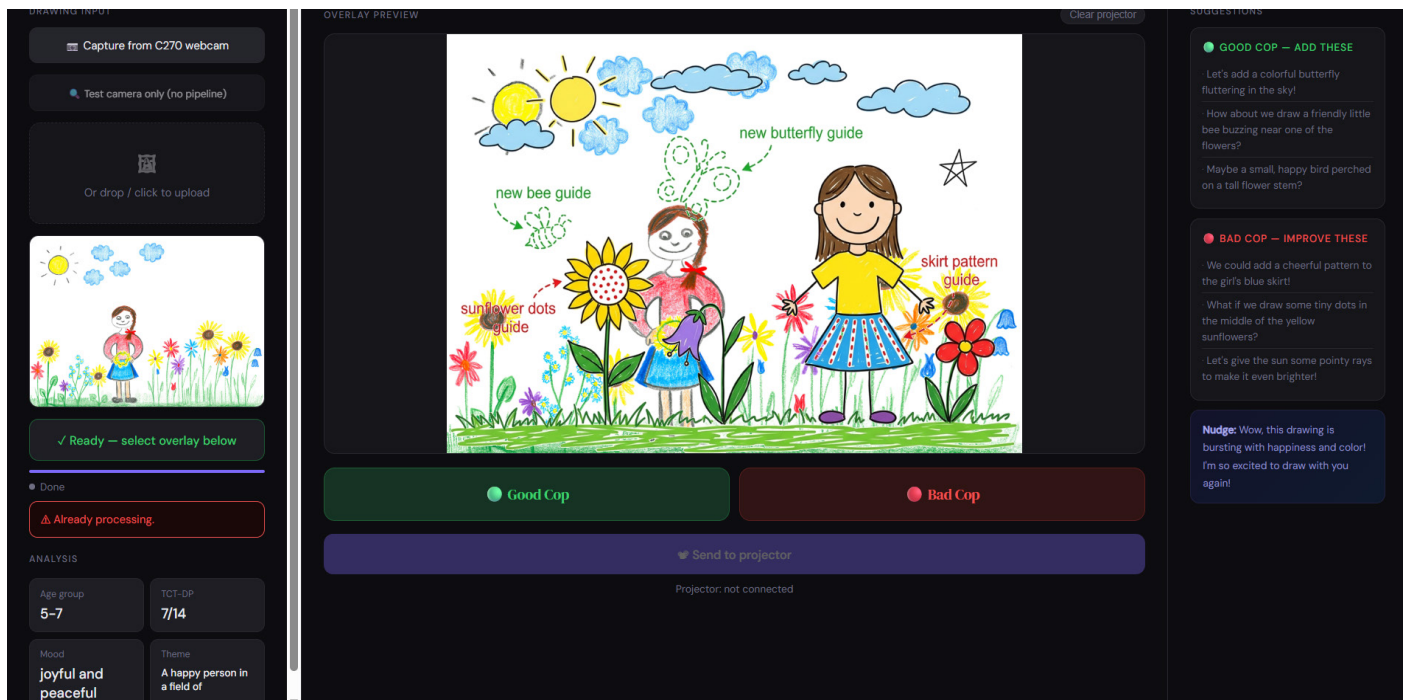


Figure 79: Analysis dashboard v4

Focus: a continuous loop

The fourth version made the system continuous. It introduced a persistent camera feed and session state, so that instead of processing a single static image, the prototype could keep watching the paper and re-analyse the drawing as it developed over time.

This shift was essential to the concept. The intervention was always intended to support a “back-and-forth” between child and robot, and that is impossible with a one-shot analysis tool. Holding a live feed and a persistent session transformed the prototype from something that inspected a finished drawing into something that could accompany a child while they drew, generating fresh suggestions as the work grew.

With this in place, the interaction became a repeatable, session-ready loop – the foundation for the real-time, projected co-creation that the final version would deliver.

Version 5 - Le Magique Drawing

ANALYSIS

THEME Nature Scene With A Person	INFERRED AGE 5-7
MOOD Happy	ENERGY Moderate

clarity: clear

representational

schematic

spontaneous

OBJECTS IDENTIFIED

yellow sun with rays

four blue clouds

green grass

variety of colorful flowers (yellow sunflowers, red, blue, purple, orange, bluebells) with green stems and some leaves

a girl with brown hair in a braid with a red bow

a girl wearing a red long-sleeved shirt and a blue skirt

a girl with brown shoes

a yellow circular object with a blue star being held by the girl

layout: The sky elements (sun, clouds) are at the top, the girl and flowers are in the mid-ground, and grass is along the bottom.

detail: moderate

COLOURS

green

yellow

blue

red

brown

variety: high

STRENGTHS

- Vibrant use of multiple colors for flowers and sky elements.
- Clear and expressive depiction of a girl enjoying a flowery field.
- Good variety in flower shapes and sizes, creating a rich foreground.

GAPS

- Many flower stems do not have leaves.
- The sun does not have a face or expression beyond rays.
- There are no animals or other interactive elements in the scene.

Figure 80: Analysis dashboard v5

Focus: refocus on the child

The final version was a consolidation and rebuild that refocused the entire system on the child-facing experience, and marked the point at which the prototype was renamed from an "Analysis Dashboard" to 'Le Magique Drawing'.

Several substantial changes converged here. The TCT-DP score, initially thought useful, was ultimately removed as the AI's scoring of the drawings proved too inconsistent and unreliable to be meaningful. An attempt was made to correct this through the same manual-feedback process used elsewhere in the system, but the system was unable to learn from it. Overcoming this limitation would require constructing a dataset of drawings already scored against the TCT-DP scoring chart and feeding it to the AI as a benchmark for how drawings should be rated. At present, the system draws only on the methodology of the TCT-DP scoring chart; it has no grounded reference of pre-scored drawings against which to validate its own scores. A promising direction for future development would be to train a VLM on such a scored dataset to achieve accurate and reliable results.

A third creative lens – imagination (the Wild persona) – was added alongside additions and realism, because two sensible voices seemed to be lacking the nudges to spark the divergent, humorous invention that children thrive on. Three spoken engagement prompts were introduced, one in each personality's voice, with humour calibrated to the child's age. The analysis itself was enriched to capture missing objects, colours, developmental milestones, and strengths and gaps. Finally, the interface was polished and the live projector integrated, closing the loop between the AI's suggestions and the physical paper.

The rationale behind the rebuild was a clarification of purpose: rather than attempting to score a child's creativity – which the model could not do reliably – the system's value lay in delivering actionable, age-calibrated, projectable nudges through an expressive set of personalities. This was the version taken forward into testing with children.

5.3.1.2 Multiple Personas Suggestions

The analysis stage produces an internal understanding of the drawing, the persona stage turns that understanding into something the child can act on. The central design decision is to offer not one suggestion but several, each from a different “voice.” A single, neutral suggestion engine would tend toward one prescriptive answer – effectively telling the child what to draw next. Multiple personas instead present several creative lenses on the same drawing: different, even contradictory, directions the child can take. This preserves the child’s agency as the author of the work, the robot proposes, the child chooses, and reframes the interaction as a genuine back-and-forth rather than instruction. It responds directly to the workshop and interview findings, where children needed nudges and feedback to sustain a creative task, yet where over-direction risked overriding their own ideas.

Each persona is realised as a distinct prompt that takes the shared structured analysis together with the child’s original drawing and produces two outputs: a set of suggestion marks and a short textual prompt. The marks are generated as light, dashed “tracing guides” – the outline of the suggested thing, drawn in the persona’s colour – which are projected directly onto the child’s own paper, where they can trace over them, adapt them, or ignore them entirely. Every persona is age-calibrated: the same drawing yields simpler, single-shape suggestions and basic vocabulary for a 2–4-year-old, and more detailed, narrative suggestions for an 8–11-year-old, driven by the age the analysis inferred. The three personas run on the same drawing, and one selected by the child is surfaced. The child has the ability to switch between the multiple personas as they please. However, the child engages with only one clear voice at a time while the others remain available.

The three personalities:

1. Optimist (green) – “what to add.” An encouraging collaborator that looks for what the scene could gain. It suggests realistic, contextual new elements that naturally belong in the drawing and extend the story the child is already telling, while deliberately avoiding generic clichés. Its role is to celebrate and build upon the child’s work.

2. Pessimist/Realist (red) – “make it real.” A grounded reviewer that asks what would make the scene more believable as a real place. It points to the missing real-world parts of what is drawn – a door on a house, wheels on a car, water around a fish – always as a concrete thing the child can draw, never a vague critique or

a minute nitpick. Its role is to nudge the drawing toward plausibility without diminishing it.

3. Wild Mad Scientist (purple) – “wild ideas.” An absurdist inventor that reimagines what the child drew. It proposes playful, impossible transformations – revealing that an object is secretly something else, or asking “what if” in increasingly clever ways with age. Its role is to break the rules of the scene and spark divergent, humorous invention.

The personas were chosen because, together, they span three complementary creative moves rather than three flavours of the same one: build on it (Optimist), make it real (Realist), and break it open (Mad Scientist). The first two emerged directly from the selected Multiple Personality Robot concept, whose contrast between an encouraging and a critical voice gives the child two perspectives to react to.

The third, the Mad Scientist, was added during prototyping to inject the playful, divergent dimension the other two lacked – and it answers a specific finding: that older children (8–11) are triggered by humor and frequently stall at the start, needing a spark to push past it. The workshops had revealed a telling gap. Children’s imaginations “ran very wild” while brainstorming, yet they consistently self-censored, ruling ideas out as unbuildable, refusing to leave their comfort zone, and, among the 8–11s, showing “a general lack of wild ideas... and self-imposed creative restriction.” This complicates the assumption that children are spontaneously divergent and need only freedom; given freedom, these children converged and stalled. It aligns instead with the divergent-thinking account in the literature and with Vygotsky’s view of imagination as combinatorial and extendable through scaffolding: divergence had to be actively invited, not merely permitted. The Wild persona was therefore conceived as a divergent scaffolder. To act as a provocateur that suspends the rules of the scene and models the imaginative leap the children were reluctant to take unaided. While remaining one optional lens among three, so that the nudge never overpowers the child’s authorship and imagination.

The three voices also give the robot a legible identity: each persona maps to a distinct physical expression on the embodiment, so the child can read which voice is speaking through the robot’s eyes and posture as well as through the projected marks. Above all, offering three contrasting lenses and letting the child choose between them. This keeps the child in control of their own creation, which is the central piece of co-creation.

Version 1 - Two Personalities

GOOD COP / BAD COP FEEDBACK

Good cop

- Rich and varied use of colors to create a lively scene.
- Clear and cohesive theme of a joyful outdoor experience.
- Good spatial organization with a clear baseline.
- Demonstrates imagination and positive emotional expression.

Bad cop

- No explicit narrative or story beyond the visual scene.
- Lack of depth or perspective beyond basic arrangement.

IMPROVE

- Exploring simple ways to show objects further away or closer

ADD NEXT

- What is the special story behind the object the girl is holding?
- Can we imagine what sounds or smells might be present in this garden?
- Try adding different textures or patterns to the flowers or clothing.

Figure 81: Suggestion nudges v1

Focus: add & critique

The suggestion system began with two contrasting voices layered onto the analysis. The Good Cop (Optimist) suggested what to add – new elements the child could bring into their drawing – while the Bad Cop (Realist) pointed out what to fix – details that would make the drawing more complete or believable. Together they offered two opposing perspectives on the same piece of work.

The decision to use two contrasting personas, rather than a single advisor, was deliberate. Presenting the child with an “add” voice and a “fix” voice turns the interaction into a choice rather than an instruction, keeping the child in control of which direction to take and reinforcing their ownership of the drawing.

This established the core mechanic of the whole system. Its limitation, however, was immediately apparent: generated from prompts alone, the raw suggestions were generic and frequently did not fit the specific drawing in front of the child. The personalities had the right intent, but not yet the right content.

Version 2 - (+ Manual Fine-Tuning)

GOOD COP / BAD COP

Good cop

- Your drawing is so full of life and color, like a real field of flowers! You created so many different kinds of flowers and made a wonderful scene. The special object your character is holding is really unique and makes us wonder about its story!

ADD NEXT

- What if there were some little creatures hiding in the grass, or maybe a tiny house or a path leading somewhere in the background?

Bad cop

- You've created a great flat picture, and thinking about how some flowers could hide behind others might add even more depth.

IMPROVE

- You could try drawing the person's arms so they look more like they are really holding that special object, or maybe try making some flowers look closer and some farther away.

Tell me about all the different kinds of flowers in your picture! And what is that wonderful shining object your character is holding? What makes it so special?

Figure 82: Suggestion nudges v2

Focus: make them make sense

The second stage addressed that inconsistency with a human-in-the-loop feedback loop. Because the underlying model could not be fine-tuned directly, an alternative means of steering it was devised: each drawing was run through the pipeline, its generated suggestions were manually reviewed and rated, and the researcher's feedback was compiled into a persistent context file. This file was appended after every run and fed back into every subsequent generation, gradually tuning the model's behaviour towards more sensible, targeted output.

The rationale was practical. The raw suggestions were too inconsistent to rely on, and without direct access to fine-tune the model, a human-in-the-loop process was the most effective way to raise their quality to a dependable level – encoding, run by run, what a good addition or a sensible improvement actually looked like.

This proved highly effective at producing targeted suggestions. It also introduced an important caveat that is carried forward as a limitation of the work: the loop embeds the researcher's own subjective judgement of what counts as a good addition or a realistic improvement, so the tuned system inevitably reflects a degree of personal bias.

Version 3 - (+ Grounded & Age-Calibrated)

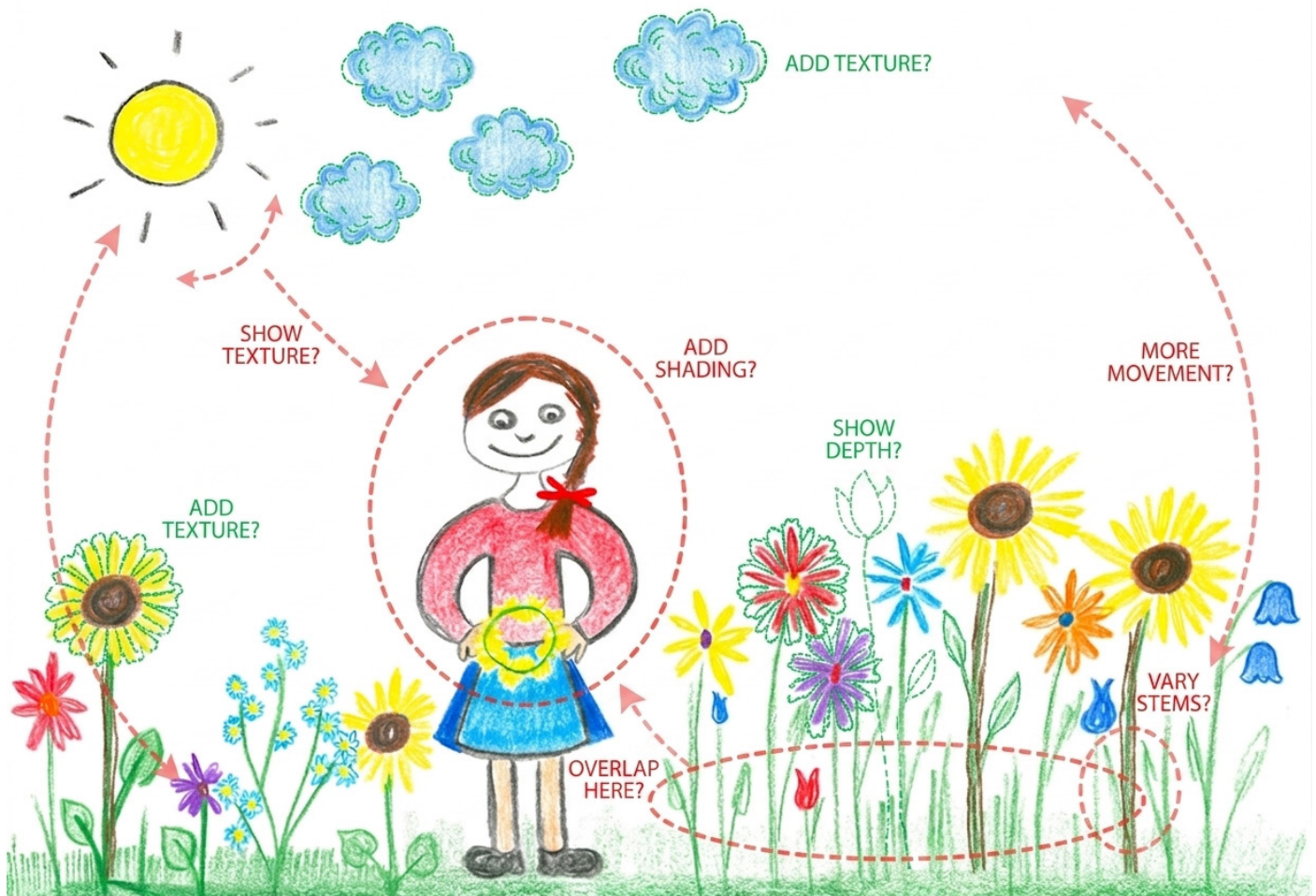


Figure 83: Suggestion nudges v3

Focus: specific & age-fit

The third stage tackled two remaining weaknesses at once. First, the suggestions were grounded: they were now required to reference the objects actually present in the drawing, and the model's habit of reflexively defaulting to generic elements – clouds, a sun, a bird – was explicitly banned. Second, they were age-calibrated: each suggestion was tuned in both complexity and vocabulary to the child's developmental bracket, spanning the 2–4, 5–7, and 8–11 age groups.

Both changes responded to clear failings. Suggestions had been ignoring the child's own work, proposing additions that bore no relation to what was on the page; and a single, one-size prompt simply could not serve both a toddler and an eleven-year-old, since what delights a three-year-old is trivial to an older child, and what challenges an older child is incomprehensible to a toddler.

The result was suggestions that were at once specific to the individual drawing and appropriate to the individual child – a substantial step towards nudges that felt genuinely personal.

Version 4 - (+ Refinement & Optimization)



Figure 84: Suggestion nudges v4

Focus: balance & polish

The fourth stage refined and tuned the suggestions further – sharpening the accuracy of the generated elements, improving where objects were placed, and making the overlays more contextually aware and richer. Additionally, it identified and removed a gender bias from both the wording of the suggestions and their underlying ideas.

During development it had become apparent that the generations could skew by gender – the more imaginative suggestions, for example, tended to default towards stereotypically “boyish” scenarios. The prompts were adjusted so that the system no longer took gender into account when analysing a drawing or producing suggestions. The motivation was fairness. For the intervention to serve every child equally, its nudges had to be balanced and neutral – never pushing a child towards gendered content, and reading consistently regardless of who the child is.

This produced a fairer, more even-handed set of suggestions, ensuring the creative direction offered to a child came from their drawing rather than from an assumption about them.

Version 5 - (+ Third Personality Added)



Figure 85a: Suggestion nudges v5 images

Focus: spark imagination & polish

The final stage introduced a third “wild card” lens – the Mad Scientist (Wild) persona – offering absurd, imaginative transformations of the objects the child had drawn, alongside a broad polishing pass that made every suggestion concrete and coherent. The marks were now drawn as traceable outlines of the actual thing rather than boxes around empty space; the reflexive default of adding a ground line was removed; the imaginative ideas were made sophisticated enough not to feel babyish to older children; the text shown to the child was matched to the marks actually projected; and each personality's suggestion was paired with a voiced engagement prompt.

The rationale was twofold. Two sensible voices had proven insufficient: a third, playful lens was needed to spark the divergent, humorous invention that older children in particular thrive on. And, across all three personalities, each nudge finally had to satisfy a strict standard – it had to be genuinely drawable, specific to the child's work, and true to what was actually projected onto the paper.

This yielded the final three-personality suggestion system – additions, realism, and imagination – that was carried forward into testing with children.

ENGAGEMENT PROMPTS

● Optimist

Wow, what a bright and happy scene! What if we drew a little butterfly fluttering over these lovely flowers?

● Pessimist

Hmm, this sun looks very warm and bright, but where's its special sun hat to keep it from getting too hot?

● Mad Scientist

Aha! I wonder what would happen if we gave the girl's braid a secret lever, and when she pulled it, all the flowers started singing?

SUGGESTIONS DRAWN ONTO THE OVERLAYS

● Additions

- a dashed butterfly with 'Butterfly!' written next to it on the top right
- a dashed ladybug with 'Ladybug!' written next to it on a leaf on the left

● Realism

- red dashed lines and the word 'bone' near the girl's feet
- a brown bumpy pile of dirt with red dashed lines and the word 'soil' on the right grass

● Imagination

- A happy melting candy on a stick is in the sky.
- Purple drips are falling from the clouds.
- Purple zigzags go from the girl's hands to the flowers.

Figure 85b: Suggestion nudges v5 engagement prompts

5.3.2 Integrated Workflow

Brought together, the system runs as a continuous co-creation loop – a genuine back-and-forth in which the robot proposes and the child decides. The child draws freely on paper; the camera continually records the drawing and sends a new image frame for analysis every 30 seconds; and the three personas each read that same analysis to generate an age-calibrated output: a set of dashed suggestion marks, each in its own color.

One of the three personas – Optimist, Realist, or Mad Scientist – can then be selected (by the researcher, or, in the envisioned final use, by the child through a physical token/button), and its marks are projected directly onto the child's own paper as light tracing guides. The child can switch between the multiple personas whenever they wish, the generated overlays remain until a new one is requested.

Crucially, the suggestion is only ever an offer: the child can respond however they wish: tracing over a guide, adapting it into something of their own, or ignoring it entirely. Then keep drawing, at which point the loop begins again with the child selecting a persona.

Each pass hands authorship straight back to the child, so the drawing grows through a real exchange rather than instruction. In this way the system continually offers fresh, contextual, age-appropriate nudges while the child remains, at every turn, the sole creator of the work.

For the proof-of-concept, a Logitech C270 camera was paired with a Cahaya 2026 projector, and the entire setup ran through the pipeline on a computer that called the Gemini API live throughout the workflow. Figure 89 presents this co-creation workflow as a detailed flowchart. This is the main framework that is tested and evaluated in the following chapter.



Figure 86: Logitech C270 Camera



Figure 87: Cahaya 2026 Projector

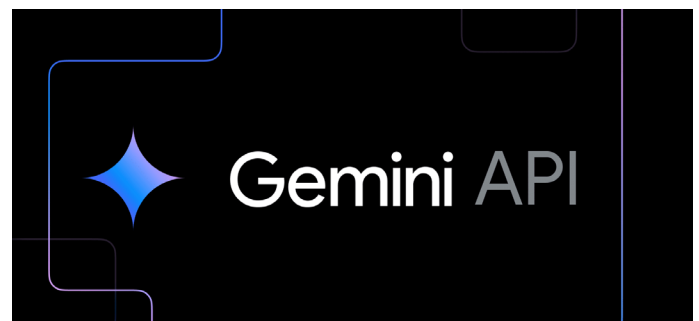


Figure 88: Gemini API

Le Magique Drawing – How it works with the child

□ Optimist · additions

□ Realist · realism

□ Mad Scientist · imagination

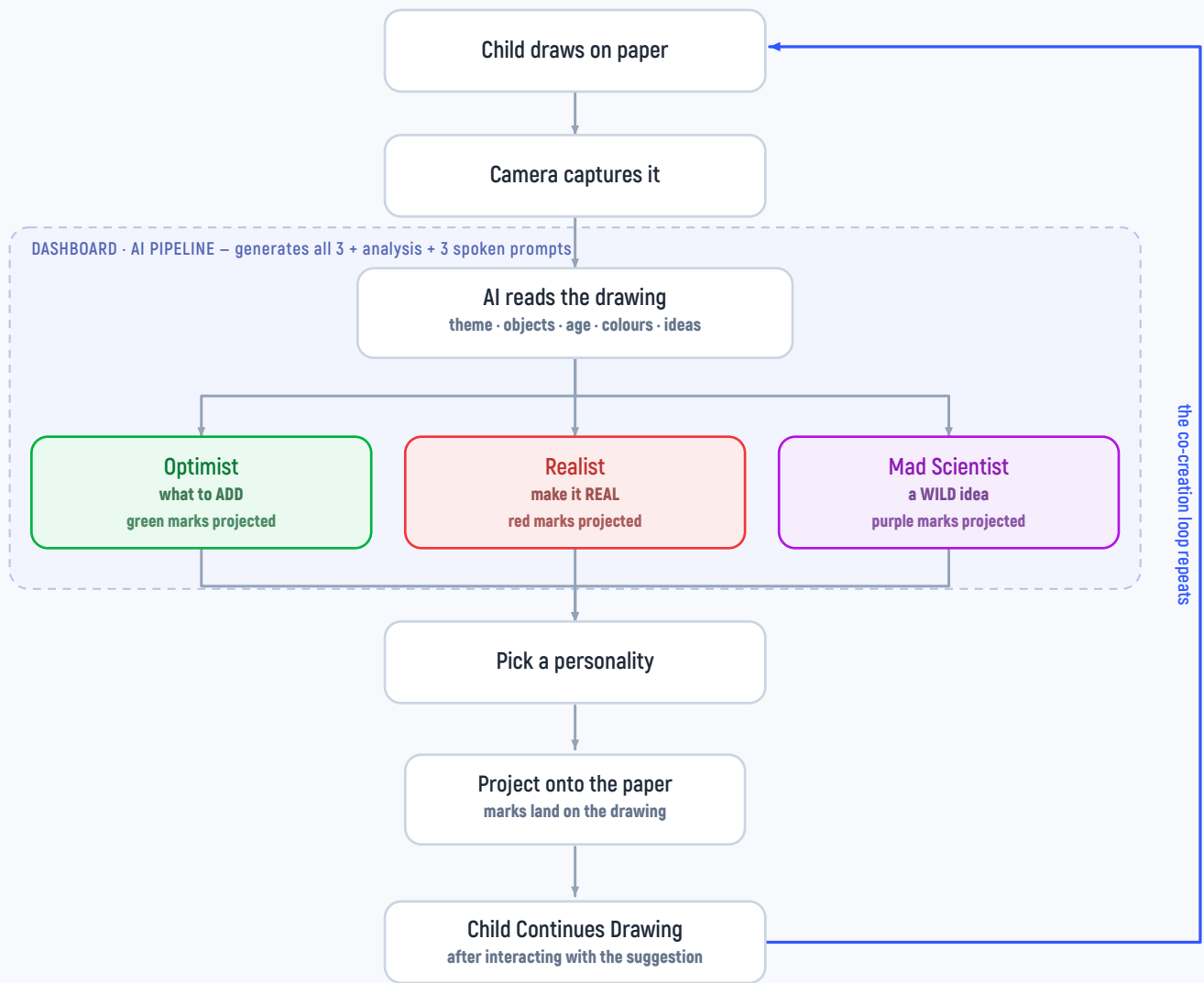


Figure 89: Co-Creation Workflow

6. Evaluation

6.1 Thematic Analysis

6.2 Observations (2-4 Years)

6.3 Observations (5-7 Years)

6.4 Observations (8-11 Years)

6.5 Results

6.6 Design Insights

6.1 Thematic Analysis

To test the design of the co-creative workflow, the following experiment was conducted with the children who had taken part in the co-design workshop. The observation focused on how participants interacted with the three personality-based suggestions (additions, realism, and imagination), how these interactions varied across age groups, how the device influenced their drawing actions, how the AI responded in turn, and their overall experience of this new co-creative workflow.

For each age group, I began with a group demonstration explaining how the device works, how it generates a response, and the sort of personality each projection represented. I then conducted a trial run, drawing collaboratively with the device myself, so that participants could become familiar with the device and the workflow before their own session.

The Task

Each participant was given a blank sheet of paper and asked to start drawing freely – there was no set subject or prompt, so that the drawing would emerge from the child's own imagination. As the participant drew, the device continuously observed the paper, analysed the drawing, and projected personality-based suggestions onto it that the child could choose to trace over, build on, or ignore. The open, blank-paper starting point was chosen so that the co-creation would begin from the child's own idea rather than a predetermined image, allowing the influence of the device's suggestions on an evolving drawing to be observed.

The prototype was operated in a Wizard-of-Oz manner: I controlled the suggestions, manually switching between the generated overlays, asking each participant which one they wanted, and then letting them continue with their drawing. The device generated a new suggestion every 30–60 seconds, depending on the image-generation time. Once a new suggestion had loaded, I asked the participant whether they wanted to use the new suggestion, continue with the previous one, or keep the projection blank. Each session lasted 15–20 minutes per participant. Participants were drawn from the 43 children who had taken part in the co-design workshops; of these, 26 were available to return for the evaluation. The 2–4 year group included 10 participants, the 5–7 year group 8, and the 8–11 year group 8, for a total of 26 children across the three age groups.

Data Collection & Analysis

The experiment was analysed using qualitative methods, drawing on three sources of data: the video recordings of each drawing session (capturing the evolving drawing), my own observation notes taken during and immediately after each session, and a short open-ended interview in which I asked participants about their experience of drawing with the device. The interview covered the quality of the suggestions and how they were received, the child's experience of the workflow, the impact of the system on their drawing process, and their perception of the embodied AI.

The recordings were analysed inductively, following a thematic analysis approach (Braun & Clarke, 2006). I first familiarised myself with the material by repeatedly watching the recordings, then openly coded the behaviours and reactions that emerged, and grouped these codes into broader themes. Rather than testing fixed hypotheses, the coding remained open to whatever patterns arose, while being sensitised to several dimensions of interest: the child's level of engagement and attention, how they took up the suggestions (accepting the new one, keeping the previous one, or choosing a blank projection, and which of the three personalities they gravitated towards), how the projected marks changed what and how they drew, the turn-taking and co-creative workflow between the child and the device, expressions of creativity, conformity, or surprise, and any moments of confusion, hesitation, or frustration.

Finally, the themes were compared across the three age groups to surface how the interaction with the device, the effect of the different personalities, and how the overall co-creative experience differed between younger and older children.

6.1.1 Experiment Set-Up



Figure 90: Experiment set-up with the projector and camera attached.

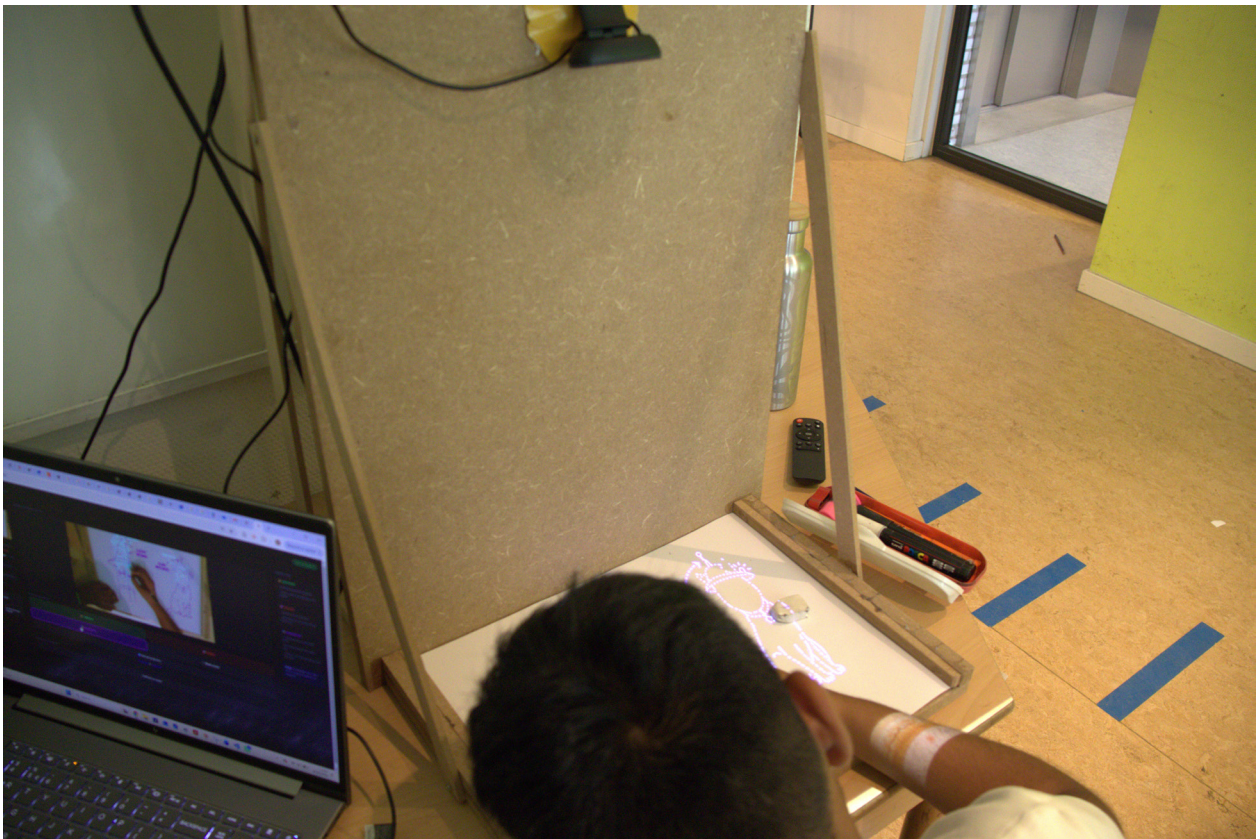


Figure 91: Experiment conducted with a WoZ manner, manual switching of suggestions.

6.2 Observations (2-4 Years)

For the youngest age group, the AI was treated less as a collaborator offering options and more as an authority to be followed. There was a strong tendency to trace directly along the projected lines, and the children consistently deferred to the AI companion's suggestions rather than weighing them as choices.

This deference, however, was not absolute: in several instances a child accepted a suggestion but then produced their own version of the element instead of sketching along the projected guide, retaining a degree of ownership over the mark-making even while following the AI's lead.

A clear pattern of completionism ran through this group. The children wanted to draw all three suggestions, one after another, and felt a need to finish whatever they had started before doing anything else. Even when told that a new suggestion was ready, they preferred to complete the current element first before moving on – the arrival of a fresh suggestion did not interrupt the task in progress. This age group also relied on the device to initiate the activity: in every case, a child would first draw a small mark on the paper and then pause, waiting to see what the device would suggest before continuing.

Comprehension was a limiting factor. Some suggestions were confusing for this group, particularly the realism (realist) personality, as the children struggled to understand what the suggestion was asking them to fix or improve. The imagination (wild) personality was likewise barely taken up, used by only one of the eight participants, indicating that the more abstract and interpretive suggestions were less accessible at this developmental stage.



Figures 93a & 93b: Children tracing the generated element.



Figure 94: Child taking inspiration and then drawing in another place on the paper.



Figure 92: Child writing the text projected.



Figure 95: Child drawing projected elements without tracing.

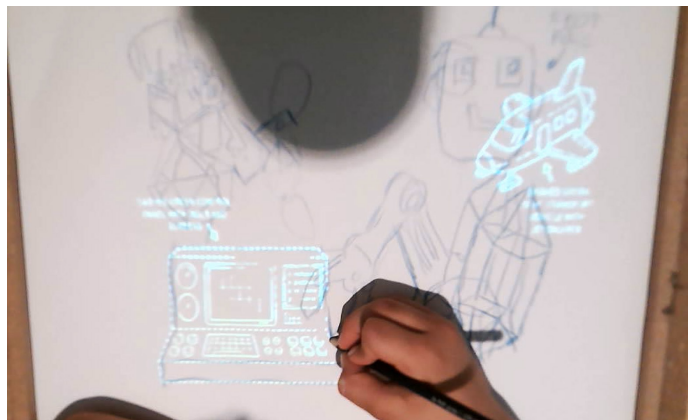
6.3 Observations (5-7 Years)

Participants in this age group took up the suggestions readily and were noticeably impressed by how the system interpreted their drawings, expressing a sense that the device genuinely understood what they had made. They were highly focused throughout the task and repeatedly wanted to continue past the allotted time, indicating a strong state of engagement and flow. This engagement was driven by curiosity about the suggestions: the children continuously asked for new prompts, often leaving an element unfinished because they were more interested in discovering what to do next than in completing what they had started.

The additions (optimist) and imagination (wild) personalities were by far the most popular choices, favoured by seven of the eight participants, and both were received as genuinely humorous, the children would laugh and chat with me about these suggestions. A common workflow emerged across the group: a child would draw something, accept an imagination (wild) suggestion and complete it about halfway, and then switch to the additions (optimist) suggestions for the remainder of the drawing. One participant diverged from this pattern entirely, taking only the realism (realist) suggestions and steadily adding suggested element in turn to their drawing.

The suggestions were, at times, powerful enough to redirect a child's intent. In one case, a participant drew a face, waited for a suggestion, and on seeing it, decided to start over on a fresh sheet in order to draw the suggested idea first, letting the device's proposal take over their original plan.

As each session progressed, the drawings became increasingly detailed. This escalation reached a point where the analysis AI no longer recognised the drawing as belonging to the child's own age group and reclassified it within the older bracket, an indicator of how much the elements had matured over the session. This group also sought more control over the output than the prototype allowed: several children wanted flexibility in the placement of the projection and asked me to move it. As repositioning was not possible in the current setup, I explained that they could simply draw the suggested element in a different location on the paper than where it was projected.



Figures 96a, 96b & 96c: Consistent acceptance of the optimist personality and fully drawing the generated overlays



Figures 97a, 97b & 97c: Constant and consistent engagement of the suggestions led to more detailed sketches.

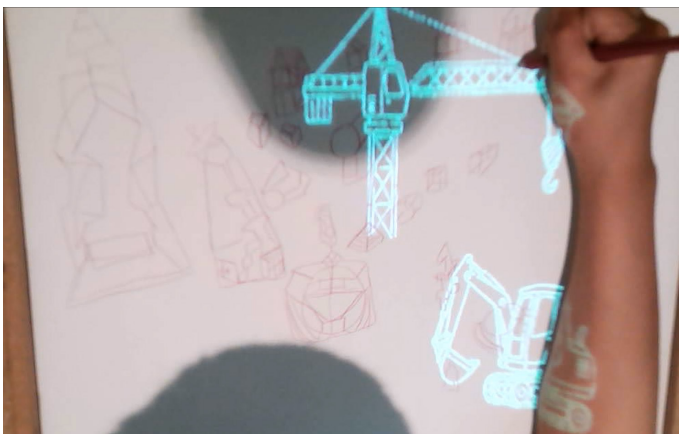
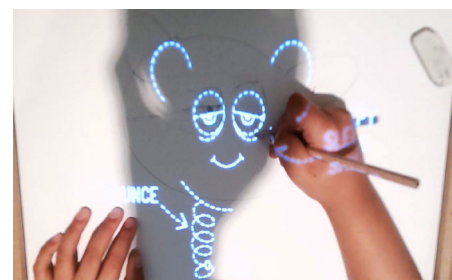
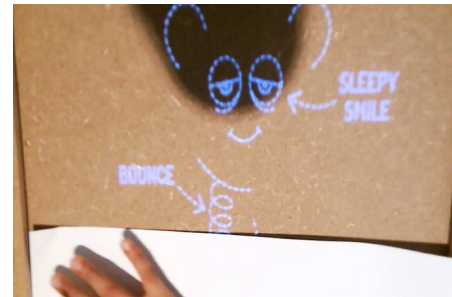
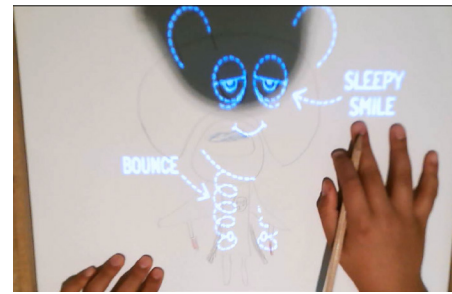
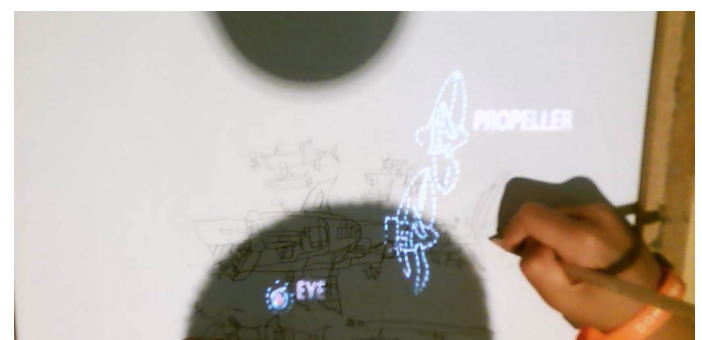
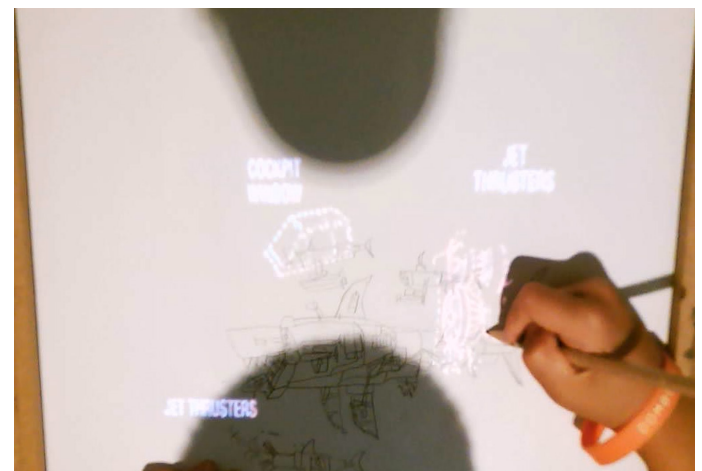


Figure 98: Detailed suggestions offered higher engagement level.



Figures 99a, 99b & 99c: Changing drawing direction and starting from blank to follow the suggestion.



Figures 100a & 100b: Consistent use of the realist personality to improve the element drawn.

6.4 Observations (8-11 Years)

The central observation from this age group was the presence of two contrasting entry points into the activity. Some children came in with a detailed, preconceived idea that they wanted to draw out properly over a longer period before receiving any suggestions, while others had no idea where to start and would begin with something abstract (shapes or scribbles) and then wait for the suggestions to build on. This distinction between the planner and the explorer shaped when, and whether, the suggestions were used at all.

Half of the participants arrived with a clear idea of what they wanted to draw, and throughout their drawing process they refused the suggestions whenever something was prompted, preferring to wait until their drawing was more detailed and fully sketched out before considering any input. For these children the device was often a source of frustration, as the suggestions did not always align with what they had envisioned. They held pre-conceived expectations of what the suggestions ought to be, and at times explicitly expressed that the system had failed to generate the elements they were hoping for.

The other half drew exploratively from the outset, and for them the workflow came far more naturally. These participants took up the realism (realist) suggestions quite often, particularly when drawing the facial structures of their figures. Indeed, difficulty with faces was shared across the whole group: all of the children conveyed that it was hard to draw facial features (eyes, mouths, and noses) with particular emotions, and they found that the projection helped them accomplish this. Not every child remained engaged, however; two participants disliked the suggestions being placed on their drawings, lost interest after about ten minutes, and chose to leave the task.

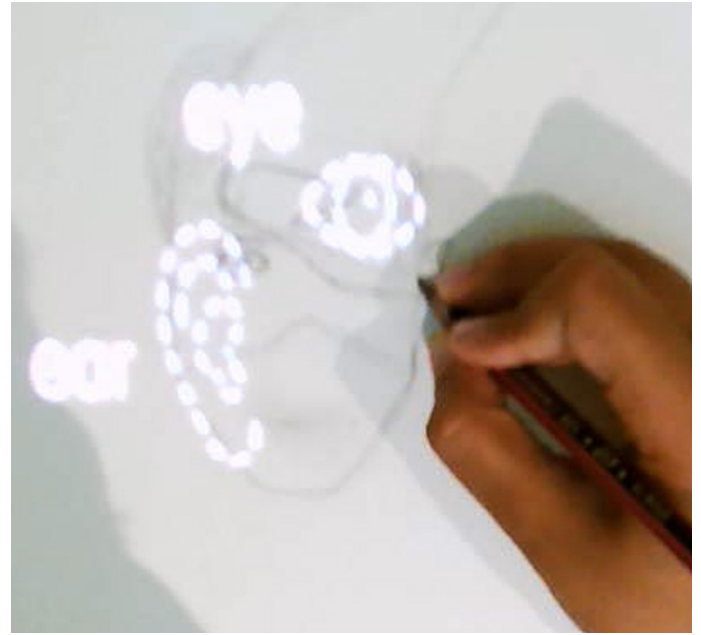


Figure 101: Acceptance of facial features in planned drawings.

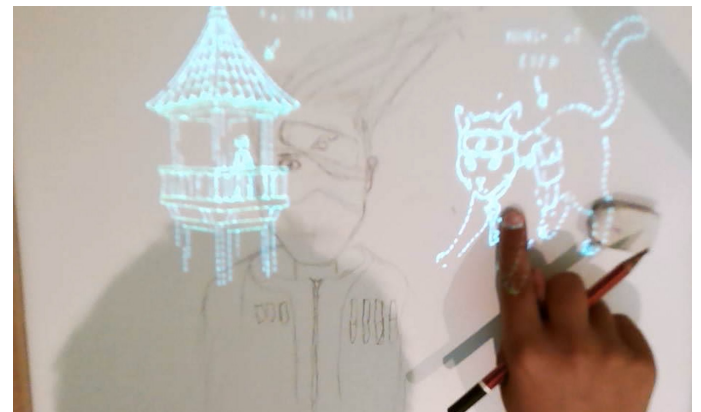


Figure 102: Recognition of popular, well-known character enabled context-aware suggestions – referencing the character and their world.

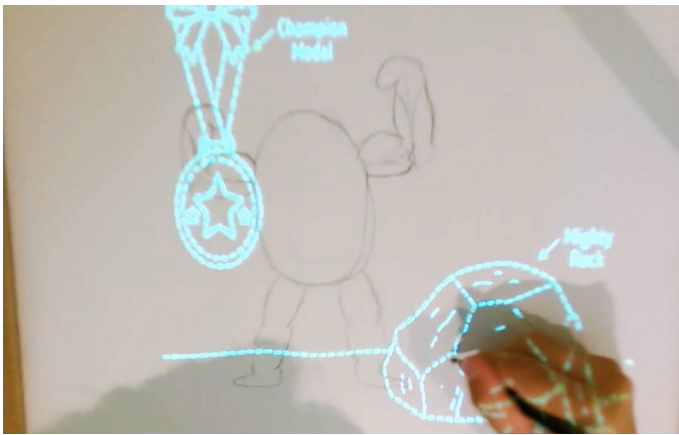
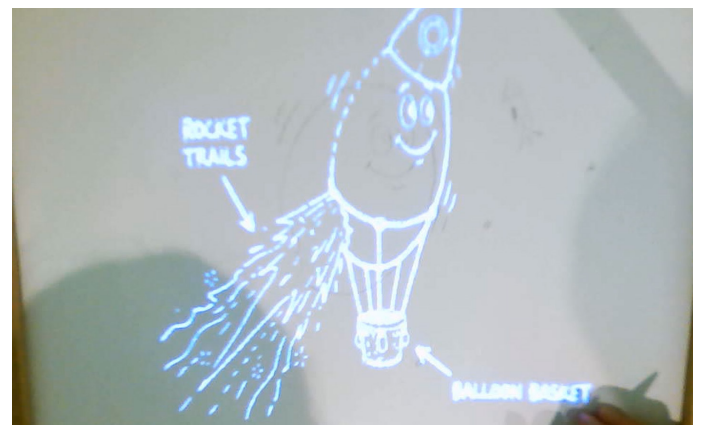
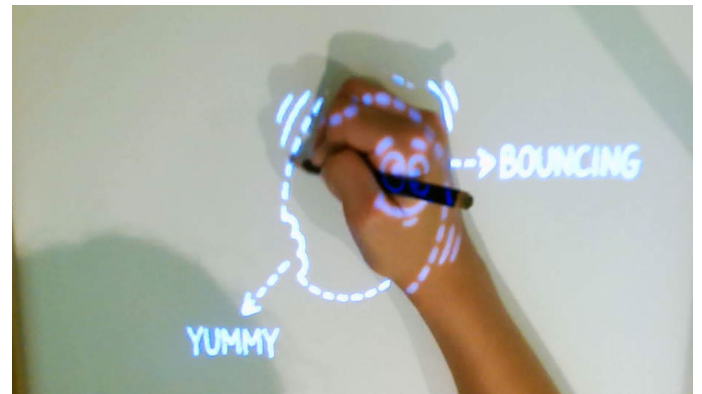
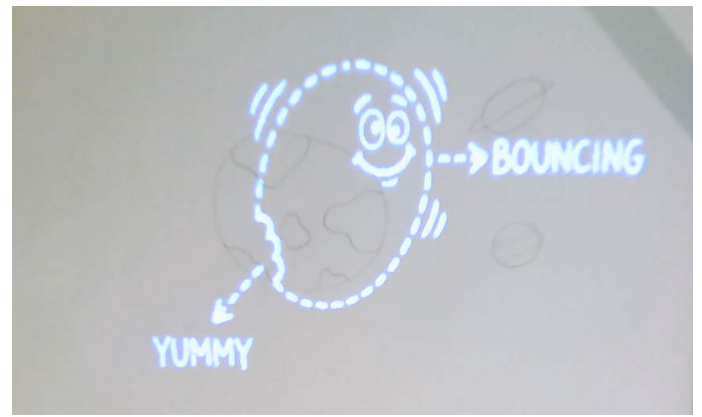
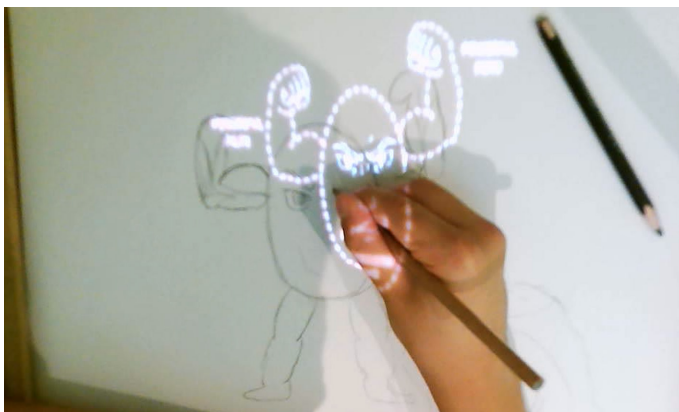
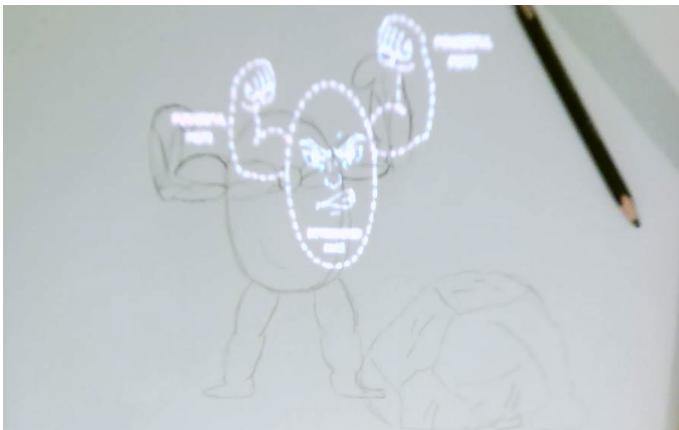


Figure 103: Planned drawers waited till the sketches were more detailed before accepting suggestions.



Figures 105a, 105b & 105c: Improvised drawer waited for immediate suggestions and then built further on it.



Figures 104a & 104b: Acceptance of facial features by the realist personality in drawings.

6.5 Results

Building on the observations from the tests and the codes derived from them, six major themes emerged that together offer both validation of, and further insight into, the prototype. Prior to the tests, the analysis was intended to focus primarily on a set of predefined directions: the child's level of engagement and attention; how they took up the suggestions (accepting a new one, keeping the previous one, or choosing a blank projection) and which of the three personalities they gravitated towards; how the projected marks changed what and how they drew; the turn-taking and co-creative workflow between the child and the system; expressions of creativity, conformity, or surprise; and any moments of confusion, hesitation, or frustration. During the experiments, however, two further and unanticipated patterns emerged. The first concerned the point in the drawing process at which the suggestions should be triggered for generation and projection. The second was the tendency, in certain cases, for the AI to become a constraint on the child's drawing rather than a scaffold for it.

The behavioural differences reported below were all directly observed in the sessions and are grounded in the video, notes, and interviews. However, the extent to which they generalise to a wider population remains unclear, given the small sample size. The patterns should be read as indicative rather than representative, pointing to tendencies worth investigating at scale rather than to established, generalisable effects.

The six themes are discussed in turn below: Collaboration Role of AI, Drawing Actions, Reception of Personas, Suggestion Trigger Time, Engagement Response, and AI: Scaffolder vs. Constraint.

6.5.1 Collaboration Role of AI

The collaborative role that the AI took on differed markedly between the age groups.

The 2–4 year group perceived it as an authoritative figure, and the children were inclined to replicate the projection exactly – drawing over the projected lines and even copying the text labels. They also wanted to complete the entire projected suggestion before moving on to any other action, almost as though compelled to finish it.

The 5–7 year group, by contrast, saw the AI more as a playful partner and received its suggestions with humour. They would take up a suggestion but, partway through completing it, either ask for another or set off in their own direction, treating the AI's input as a spring-

board rather than an instruction.

The 8–11 year group wanted to assert their own authorship and were often at odds with the AI. They were more inclined to defer the suggestions until their drawing was more detailed and developed, engaging with the device on their own terms rather than the AI's.

6.5.2 Drawing Actions

There were diverse amounts of drawing actions that emerged from during the co-creative drawing session. But none were exclusive to any age group, most of the participants were generally inclined to copy the projection exactly, some connected their own ideas to the suggestion by using it as an inspiration.

Some participants from the older age groups (5–7 & 8–11) were more eager to jump from suggestion to suggestion rather than sticking to one and completing it before moving on. In a few instances, the participants drew the initial abstract creation, saw the suggestion and wanted to start fresh on a blank paper with it.

6.5.3 Reception of Personas

Each of the three personalities – the Optimist (additions), Realist (realistic improvements), and the Wild (imaginative) persona – was received differently depending on the age group. For the 2–4 year group, the Realism suggestions were often confusing and difficult to make sense of. The Wild persona was generally ignored by this youngest group, suggesting that its ideas were too far “out of the box” for them to connect to the reference of their own drawing. The Optimist suggestions were the most popular within this group, with participants often completing the entire projected overlay before moving on with their drawing.

For the 5–7 year group, the Optimist and Wild personas offered suggestions that the children found hilarious, prompting them to become very talkative about their drawings. They would often build on the ideas from these overlays, letting their imagination run wild to make unexpected connections.

For the 8–11 year group, participants were split in half. The first half already had a plan for what they wanted to draw, and this group gravitated primarily towards the Realism suggestions, which became a tool for rendering difficult facial details such as the eyes, mouths, and noses. The other half had no plan and began with abstract shapes; for them, the Wild suggestions were especially valuable, kick-starting their drawing by offering unconventional ideas to build on.

6.5.4 Suggestion Trigger Time

Going into the test, the prototype had a standardized generation and analysis trigger time which was every 30s, but each age group had a different preference for generation and projection of suggestions. The 2-4 age group want to finish with overlay before the next one arrives, and don't want to be hurried. This meant that they were more inclined to finish the element they were drawing and got a little overwhelmed when the new suggestion popped up. But on the other hand, if the new suggestion wasn't ready by the time they were done, they got pretty restless and didn't really continue drawing.

For the 5-7 years, they wanted a constant stream of new ideas as soon as possible, and they would jump from one idea to another, while also drawing their own elements. This group also voiced a need to see the previous generated overlays, and wanted the system to remember all the previously generated suggestions so they could revisit it later. This age group wanted fast generation, re-generation and new ideas constantly.

The eldest group of 8-11 years was divided in half, one half wanted the system to wait a little bit before suggesting. This half wanted to get suggestions at a longer time interval and more detailed suggestions. Whereas, the other half wanted quick generations similar to the 5-7 years, with constant generation of new suggestions.

6.5.5 Engagement Response

The engagement response varied around for different participants, some were delighted with the recognition of elements in their drawing and how the AI companion built on it further. Some participants reached a flow state with the co-creation and had a nice synergy going on with the workflow. This was especially observed with all the participants in the group 5-7 years, however, there were also 2 participants each in the youngest and eldest group which reached this smooth workflow.

There were also two participants in the eldest age group of 8-11, for whom the suggestions didn't match the expectations. This led to frustration and ultimately, a tipping point, where they just stopped with the task.

6.5.6 AI: Scaffold vs Constraint

The final theme, which emerged during testing rather than being anticipated beforehand, concerns the dual role the AI played: at times a scaffold for the child's creativity, and at others a constraint upon it. For children drawing exploratively, particularly those who began without a fixed plan, the AI scaffolded their creative ideas, offering starting points and unconventional directions

to build on. For children working with a preconceived plan, however, it more often became a constraint, pulling against the drawing they already had in mind.

Two limitations of the current prototype heightened this constraining effect. First, the fixed placement of the projection became a significant constraint while drawing. Children could not reposition a suggestion, and were limited to either drawing it where it fell or redrawing it elsewhere themselves. So the suggestion proved to be extra cognitive load for the child. Second, the absence of any verbal input to the system meant that children had no way to steer what was generated, so the suggestions sometimes failed to match their expectations.

6.5.7 Synthesis

The aim of the prototype was to support and enhance children's creativity in their drawing. It does this through a co-creation loop: three personas (Optimist, Realist, and Mad Scientist) read the child's drawing and offer age-calibrated nudges the child can trace, adapt, or ignore. The design was built around a few key requirements: that it be age-adaptive, that it facilitate creativity, that the child stays in control, that it works as a real back-and-forth, and that the hardware feels tactile. These are what the results are measured against, and the main question is not just whether children engaged, but whether the workflow actually helped their creativity.

On that question, the signs are positive but not absolute. The clearest one came by accident: in the 5-7 group, two children's drawing was reclassified into an older age group. The system read their age correctly at first, but as they took up more suggestions their drawing grew more detailed, until it crossed into the higher bracket – a sign that the workflow genuinely raised the quality of the drawing, not just the amount of activity. Creativity also showed in the wild, funny ideas the Mad Scientist unlocked, in children taking a suggestion and making their own version of it rather than copying it, and in the engagement itself: setting aside the novelty of the artefact, all but two of the 26 participants wanted to keep going past the task time. And all of this happened while the child stayed the creator, the suggestions were always offers, never instructions. The one caveat is that this worked well for children who drew exploratively, but less so for those who came in with a fixed plan.

The way children engaged followed a developmental gradient: the youngest treated the AI as an authority to follow, the 5-7 group as a playful partner, and the eldest as something to negotiate with as they asserted their own authorship. The personas offered something for everyone – from the dreamers to the realists, from explorers to planners – with Realism even becoming

a practical tool for the eldest children when drawing difficult facial features. The choice of persona seemed to depend on the child's own personality more than their age.

The testing also surfaced two patterns weren't planned for. First, the timing of the suggestions was not one-size-fits-all: the fixed thirty-second generation suited no group perfectly. Second, the AI helped exploratory drawing but got in the way of planned drawing which was made worse by the fixed projection placement and the lack of any verbal input to steer what it generated. Together these point to a more adaptive system: one that tunes its timing to the child, gives more control over where the suggestions land and what is generated, and remembers past suggestions. In short, the co-creation workflow has solid foundations and real value, but its success was conditional: reaching full immersion, and reliably helping every child, will take finer personalisation.

6.6 Design Insights

1. Personalised Suggestion Timer

The testing revealed a mismatch between the suggestion timing that each age group needed. Although the sample was small (8–10 participants per group) the emerging patterns were consistent enough to indicate that the trigger time should not be fixed. Instead, the interval at which suggestions are generated and projected should adapt to the child's age and personality: a slower, more spaced out for those who prefer to finish an element before the next arrives, and a faster, more continuous stream for those who thrive on a constant flow of ideas. Making the timer adaptive in this way would keep the pacing appropriate to each age and sustain engagement throughout the co-creation loop.

2. Mobile Movement of Projector

During testing, several children, wanted the freedom to move the projected suggestion, and the fixed placement of the projection became a clear constraint on their creativity. Allowing the projection to be repositioned, so that a suggestion can land where the child wants it, would remove this limitation. This could be accomplished in a couple of ways: either by mounting the projector on a more flexible platform that can be physically repositioned, or by enabling the projection itself to be manipulated through hand gestures, giving the child direct, intuitive control over where the suggestion appears on the paper.

3. Integration of a Physical Embodiment of the Robot

The testing points towards complementing the workflow with a physical embodiment of the robot to act as a drawing companion. Rather than the AI being felt only through the projected marks, a physical presence would give the system a tangible character that expresses each of the personas and makes the interaction feel more natural and social. Such a companion could also help smooth over the timing gaps identified earlier: while a suggestion is being generated, the robot could keep the child engaged through expression and gesture, easing the restlessness observed when the youngest

children were left waiting. In this way, embodying the AI would not only deepen engagement but also make the overall system feel more robust and present.

4. Optimization of Workflow

During the testing sessions, the camera experienced intermittent malfunctions, most likely stemming from hardware or connection issues. On several occasions it cut out mid-recording, and the system had to be rebooted before it could resume – briefly interrupting the co-creation loop. The most probable source of the problem was the quality of the camera hardware and its USB connection. For the next iteration, there are two possible routes to address this: upgrading to a more robust camera, or introducing a self-recovery protocol that automatically re-initialises the camera whenever it goes offline. Either approach would keep the workflow smooth and reliable throughout the co-creation loop, ensuring that a technical dropout does not disrupt the child's engagement.

5. Verbal Input for the Users

Allowing children to give verbal input for the AI to take into account would address the frustration seen when the suggestions did not match a child's expectations, particularly among the eldest planners. Such input could operate at two levels. At the immediate level, a child could request small tweaks to the projected marks, steering a suggestion closer to what they want. At a broader level, the child could tell the system which mode of collaboration they want: a more exploratory approach, in which the AI and child engage in an intensive back-and-forth of ideas, or a pre-planned approach, in which the system offers slower, more detailed suggestions to support a drawing the child already has in mind. Giving children this voice would personalise the interaction and let the workflow adapt to each child's intent rather than imposing a single mode on everyone.

6. Suggestion History Storage

Current system did not account for storing previously generated layouts, and there were a few participants across all age groups who wanted to re-visit the previous generations. For further development, the system should be able to store and revisit the previously generated overlays and have them ready to be projected on demand.

7. Age Profiling (Fixed vs. Adaptive)

A significant question raised by the testing concerned how the child's age is classified from their drawing. In several instances, the more back-and-forth the system had with a child, the more detailed their drawing became and eventually reached a point where the classified age jumped into a higher bracket. This, in turn, made the generated suggestions more detailed, producing a noticeable jump in the level at which the child was drawing. This raises a genuine design decision: whether to fix the age profile at the start of a session and hold the suggestions at that level, or to retain an adaptive system (as at present) in which the profile rises with the drawing. A fixed profile keeps suggestions reliably matched to the child's actual developmental stage, whereas an adaptive one deliberately stretches the child, offering an opportunity to draw at a higher level than they otherwise would.

7. Conclusion

7.1 Discussion

7.2 Conclusion

7.3 Future Research

7.1 Discussion

Grounding the Design

The designed proof-of-concept remains at an early stage and leaves considerable room for further development. Together, the literature review, expert interviews, and co-creative design workshops made it possible to understand the intended users, to identify the key design requirements for introducing a Child-Robot Collaboration (CRC), and to begin ideating how such a workflow might take shape. These strands built on one another: insights from the literature review informed the structure of the expert interviews, which in turn informed the design of the workshops. The literature review is not exhaustive, and further work could ground the findings more thoroughly in related research; nonetheless, the range of theories it drew together helped to frame an answer to the research question – How do cognitive, social, and collaborative behaviours during creative play develop across different childhood age groups? The interviews then served a dual purpose: while the literature had shaped their structure, they also validated several of its insights in practice. Speaking with professional teachers, who work closely with children, sharpened the understanding of the design's practical requirements, and their perspectives revealed a genuine opportunity to weave technology more healthily into children's lives. Whether educational or recreational, a significant opportunity lies at the intersection of child-robot collaboration, creativity, play, and the responsible use of AI.

Co-Design Workshops

The co-design workshops opened up a rich picture of what a social-robotic intervention might look like. The decision to adopt a participatory design approach gave the ideation a solid, user-grounded foundation, and the sessions proved insightful for understanding the dynamics of creative collaboration across the different age groups. They did not always unfold as expected – there was a gap between my assumptions about the children and how they actually responded – but this gap itself became valuable knowledge for the rest of the project. The main reason for the mismatch was an underestimation of the children's cognitive and creative abilities. From the workshops, the role of social hierarchies in collaboration emerged as an unexpected but important insight: a dominant voice could easily overpower the wider creative conversation. A second insight, crucial across all age groups, was the children's need for nudges to keep engagement high. There was also a clear dis-

inction in the collaborative role the robot was expected to play across the age groups – the youngest needed a “back-and-forth” nudging robot, the middle group a “co-bot” companion to work alongside them, and the eldest a “neutral facilitator” for the group. Across all ages, the tension between creativity and conformity recurred: the children's default was to retreat to the comfort of familiar skills rather than explore the unknown. Some, for example, wanted to look up images of the animals they intended to draw rather than trust their own memory and instinct; some drew only elements they had drawn before and knew how to render; and some were daunted by the realisation that they would have to draw collaboratively on a single sheet (something they had never done) and lacked confidence in their ability to complete it.

The workshop data were analysed using thematic analysis. This method is not free of personal bias: the findings rest on my own interpretation of the raw data, and the themes are not fully independent of my perspective. They should therefore be read not as absolute truth but as one reasoned interpretation. That said, the method has clear strengths – it allowed rich, multimodal data to be analysed through a systematic process, surfacing patterns and insights that directly informed the design, and the higher-level findings remain traceable back to their source observations. The risk of misinterpretation and bias can be reduced through steps such as repeated analysis and co-evaluator assessment. Within the scope of a single graduation project, however, not every safeguard could be applied with full rigour, which leaves room for some personal interpretation, and possibly bias, to have influenced the outcome.

Ideation & Prototyping

The ideation phase began by constructing a connection matrix between the medium of communication and the co-creative activity, which generated a large number of concepts for what the prototype might become. These were then developed through preliminary sketching, allowing quick decisions about the direction to pursue; in hindsight, fleshing the ideas out more fully would have allowed a fairer comparison between concepts. The concepts were assessed using the Harris Profile method alongside personal intuition. The decisive criteria were retaining the child's authorship of the artefact and enabling a co-creative workflow built on a constant “back-and-forth” of creative actions between child and robot. To keep the scope manageable, the decision was made to first prove that collaboration worked in a one-on-one context before expanding it to multi-user collabora-

oration. The shortlisted concept combined a dual-personality robot: one positive and one negative persona, with physical, projection-based interaction during the drawing task. This pairing was intended to strengthen the child's authorship: because the medium could present arguments from opposing sides, the child would not treat the robot's word as final but could instead decide which suggestion to accept. The projection enabled the physical child-robot collaboration and the co-creative workflow, while generating the suggestions with AI models offered the flexibility for the prototype to adapt to each age group and respond appropriately.

Development of the prototype began with the analysis backend, built on the Gemini API and configured to interpret the characteristics, themes, emotions, expressiveness, inferred age of the creator, and context of a drawing. Initially, how this analysis was reached remained something of a black box, and it frequently misclassified drawings in relation to age group. To address this, the KIDO dataset (whose drawings are already labelled by context, emotion, and age) was fed into the system, refining it to the point where it could classify drawings with sufficient accuracy, although no formal test was carried out to quantify this.

The next step was to develop the nudges and actions of a dual-personality AI. Each persona was first given a clear grounding: the Optimist built positively on what could be added to a drawing, while the Realist looked for shortcomings in realism and identified what could be improved. With pre-written prompts alone, the AI struggled to generate targeted suggestions and often hallucinated, producing irrelevant results. To bring the generation to a satisfactory level, a feedback loop was introduced. As the model could not be fine-tuned directly, each generated suggestion was manually reviewed and annotated, and the image together with its comments was saved to a master log file that was appended on every new run. While this proved highly effective at producing targeted generation, the model still depended on my specific comments for each set of outputs. The system therefore carries a personal bias: what counts as a "positive addition" or a "realistic improvement" reflects my own subjective judgement. The way to mitigate this would be to replace that single perspective with a crowdsourced database of feedback, drawing on the judgements of artists, art teachers, and art critics. Pooling many informed viewpoints would dilute any one person's bias and give the model a broader, more defensible sense of what makes a suggestion good – while the range of professional lenses (an artist's, a teacher's, a critic's) would keep it from collapsing into a single "correct" style.

With both personas established, calibrated, and

tested, a third – the Wild, or "Mad Scientist", persona – was added to introduce an element of chaos and creativity into the collaborative drawing task. Grounding this persona was particularly difficult, as it required a delicate balance between letting the AI run wild and constraining it enough that its suggestions remained coherent and interpretable by the users. It was developed through the same process as the previous two. During its calibration and testing, however, I observed a gender bias in the generated elements: the wild generations tended to default towards "boyish" scenarios. To counter this, the prompt was adjusted so that the AI did not consider gender when analysing the drawing or producing suggestions. Once the personas were configured, work began on the physical embodiment of the personalities and how they might be conveyed through the non-verbal movements of a lamp-inspired robot. Digital renders are presented in the report, but the physical prototype would require further refinement and optimisation in its electrical and hardware design.

Testing

To test the proof-of-concept, the workflow was configured to run with a live camera feed and a projector. A wooden platform was built to fix the position of the paper and to hold the camera and projector in place. With this setup in place, testing was conducted with the same children who had taken part in the workshops. The testing translated the proof-of-concept from a bench prototype into a lived interaction, and the six themes that emerged from it point to a single overarching conclusion: the co-creative workflow held genuine value, but that value was conditional on how well the device adapted to the individual child. Most striking was how closely the testing confirmed what the workshops had anticipated.

The collaborative roles the children had implicitly asked for in the workshops – a "back-and-forth" nudger for the youngest, a "co-bot" companion for the middle group, and a "neutral facilitator" for the eldest – reappeared in testing as a developmental gradient in how they treated the AI itself: as an authority to follow, a playful partner to spar with, and a collaborator to negotiate with as they asserted their own authorship. That a pattern predicted in one phase was confirmed in another gives the finding particular weight, and it directly substantiates the literature's account of how children's cognitive and social capacities shift across these developmental stages.

Cutting across this age gradient, a second and less anticipated variable proved decisive: the child's entry

point into the task. Whether a child arrived as a planner, with a fixed idea to realise, or as an explorer, starting from abstract marks and waiting to be built upon, predicted which personas resonated, how quickly they wanted suggestions, and – most importantly – whether the AI was experienced as a scaffold or a constraint. This scaffold-versus-constraint tension, together with the question of when suggestions should be triggered, were the two patterns the testing newly revealed, and both point towards a design that must fit itself to the child rather than the reverse. The clearest evidence of the scaffolding effect was an unexpected one: as the children in the 5–7 group took up more suggestions, their drawings grew detailed enough that the system reclassified them into the older age bracket.

Engagement itself was bounded by how well the device matched the child: where its rhythm, persona, and suggestions fitted, the result was delight and flow, with all but two participants wishing to continue beyond the allotted time; where they did not, the mismatch produced frustration and, in two cases, disengagement.

The qualitative analysis of the prototype testing has some limitations especially with the precision and accuracy of the engagement level and engagement time. The children who worked with it were all from the same school, that means the same educational system. So, the findings cannot really be generalised towards all the educational systems over the world. The testing was also done in a 'WoZ' method, this might mean that a fully automated system might deliver slightly different observations and results.

Environmental Impact and Responsible Use of AI

One important aspect of the project that deserves discussion is the environmental impact of its heavy reliance on generative AI. Every generation with the Gemini API is processed in a large data centre, where specialised GPUs consume electricity to run the model and, in doing so, produce heat that must be removed by cooling systems. This carries two linked environmental costs: the energy of the computation itself, and the water consumed both directly, to cool the servers, and indirectly, through the electricity generation that powers them. Although providers such as Google do not publish exact per-query figures, studies of comparable systems give a sense of scale. (Li et al. 2023) estimate that a single exchange of roughly ten to fifty prompts with a large language model can evaporate on the order of half a litre of freshwater, while (Luccioni et al. 2024) find that generative tasks (image generation in particular) are the

most energy- and carbon-intensive form of AI inference, with the most demanding image models consuming close to the energy of a full smartphone charge for a single image. This is especially relevant here, because the workflow is image-generation-heavy: each co-creation cycle produces three separate overlay generations in addition to the analysis and description calls, and in the live recording mode a new set was generated roughly every thirty seconds. Multiplied across the twenty-six participants, the repeated sessions, and the many iterations required to develop and feedback-tune the personas, the cumulative water and energy footprint of the project is far from negligible.

This sits in direct tension with the project's aspiration towards a responsible use of AI: a device intended for repeated, continuous, and potentially widespread use with children would need to weigh its creative and developmental benefits against this ongoing environmental cost – for example, by adopting smaller or more efficient models, caching and reusing generations, lowering the generation frequency, or favouring providers powered by low-carbon energy and water-efficient cooling.

7.2 Conclusion

This research set out to address a growing “creativity gap”: the tendency of traditional educational frameworks, amplified by a digital landscape of instant gratification, to marginalise the divergent, playful thinking that is central to childhood development. To confront this, the project explored whether an age-adaptive embodied AI system could facilitate and nurture creative expression in children through a shared, co-creative drawing activity. The work was organised in two parts – first understanding the users, then designing the intervention – and pursued through a Human-Centred and Participatory Design process spanning literature, expert interviews, co-design workshops, prototyping, and evaluation with children across three age brackets (2–4, 5–7, and 8–11 years).

The exploration phase answered the first research part by establishing how children’s cognitive, social, and collaborative behaviours during creative play develop across these age groups. The literature, the teacher interviews, and the co-design workshops converged on a clear developmental progression: the youngest children work concretely and need continual nudges; the middle group engage playfully and socially; and the eldest draw deliberately and self-directedly. The workshops further revealed the influence of social hierarchies in group settings, a shared need for nudges to sustain engagement, and a recurring tension between creativity and conformity, in which children retreat to familiar skills rather than explore the unknown. Crucially, the collaborative role children expected of a robot shifted with age – a back-and-forth nudger for the youngest, a co-bot companion for the middle group, and a neutral facilitator for the eldest.

The design phase answered the second research part by showing that an age-adaptive, co-creative loop between a child and an embodied AI can be built without displacing the child as the author of the work. The proof-of-concept coupled an AI analysis-and-suggestion pipeline with projection-based interaction and three contrasting personas – the Optimist (additions), the Realist (realistic improvements), and the Wild (imaginative transformations) – which the child can accept, adapt, or reject in a continuous back-and-forth. The conclusion is that such a system can be concretely specified and built: a first, working design framework for an age-adaptive creative companion.

By the process-based creativity definition adopted in this thesis, the evaluation establishes that the workflow supported children’s creativity. It reliably held their interest – all but two wished to continue beyond

the allotted time – but, more importantly, the drawings themselves showed the markers of that definition in action: children explored beyond the familiar, pushing into unfamiliar territory, and transformed their ideas into something unexpected through the nudges of another agent, while remaining the true authors of their creations. The evaluation also surfaced that the embodied AI’s “say” in the drawing was enough to influence children’s drawing actions, yet left them enough freedom not to be overpowered by it. The multiple-persona design gave them a system to brainstorm with in a genuine back-and-forth, and this exchange – carried through physical interaction rather than words or text – made it more impactful. Together these findings show how a human-AI collaborative artistic system can push children’s artistic expression forward, fostering a healthy relationship in which the child treats the AI as a companion to work alongside rather than an authority to defer to.

What cannot be concluded here is the further question: whether the intervention enhances a child’s creative ability over the longer term. Establishing that would require a dedicated study measuring specific creative indicators against a baseline for children of the same age. The defensible conclusion is therefore twofold. Within the act of drawing, the system demonstrably engaged children’s creativity and pushed their creative output, and in doing so it provides a proven basis for child-AI co-creation that shows enough promise to warrant that deeper, longer-term measurement.

Two further conclusions stand out. First, age is a first-order design variable, not a later refinement: the developmental gradient anticipated in the workshops reappeared in testing – from treating the AI as an authority, to a partner, to a collaborator to be negotiated with – and the clearest sign that the intervention did more than occupy the child was a drawing growing detailed enough within a single session to be reclassified into an older age bracket, evidence that the workflow lifted the output beyond what the child would have produced unaided. Second, this value was conditional on how well the system adapted to the individual child: their entry point as planner or explorer, the timing of suggestions, and the fit between the AI’s output and the child’s intent decided whether the system was experienced as a scaffold or a constraint. Together these reframe the central design challenge – from generating good suggestions to delivering them adaptively, to each child’s age, intent, and pace – and were consolidated into a set of concrete design insights for the next iteration.

The project's contribution is therefore threefold: an account of how creative and collaborative behaviours differ across childhood age groups; an evaluated co-creative workflow and proof-of-concept that demonstrates age-adaptive, multi-persona, projection-based co-creation in practice; and a set of design guidelines for developing it further. Its conclusions must be read within clear limits: the evaluation used a Wizard-of-Oz method, a small sample drawn from a single educational setting, and short, single sessions, while the physical embodiment was realised only as digital renders and was never tested with children. Future work should build the fully adaptive, embodied, and verbally steerable system these findings call for, and evaluate it at the scale and over the timespan that "long-term creative engagement" ultimately demands – including the multi-user collaboration this project deliberately left for a later stage.

Ultimately, this work shows that an embodied AI can move beyond passive engagement to become a genuine creative companion – one that meets a child where they are and gently draws them further. In doing so, it takes a first step towards the ambition that framed the project: helping children hold on to the artist within, rather than losing it as they grow.

7.3 Future Research

Physical Embodiment

The current system lacks a physical presence for the AI, which could be added by building a robot that visibly expresses the chosen persona while the child draws. Giving the system a body in the physical world would make the interaction feel more immersive. The initial design for this robot is presented further ahead in this section, which show its resting (content) state alongside the realist, optimist, and wild states. Beyond immersion, a physical robot could also help overcome the trigger-timing limitation: it could hold the child's attention while the image analysis and overlay generation run in the background, making the system more robust and easing the restlessness observed in the youngest age group. This would bring the system closer to a true co-creative companion. As a next step, the robot's movements would need to be calibrated and tested in tandem with the projections to observe the effect of introducing a physical presence into the interaction.

Moveable Projection

On the hardware side, a moveable projection would be the most impactful addition, letting the child position and orient the projected suggestions anywhere on the page. This would directly serve the children who wanted to trace an outline on the paper but place the element somewhere else – a need the fixed projection could not meet. There are two ways to achieve it: either make the projector arm manually adjustable, so the child can simply pull it in any direction, or implement a gesture-based system in which the camera recognises the child's actions and intentions and repositions the element accordingly. Both are promising, and further user testing is needed to see which fits the workflow best.

Verbal Input

A further step would be to add verbal input to the system. At present, the child and the system can only communicate through drawing actions, which caused some frustration during testing. Verbal input would let the system adapt far better to the child's process, whether they are drawing freely or to a plan. It would also move the system beyond its current Wizard-of-Oz operation – where I acted as the intermediary – towards full automation, letting the child and the system talk directly to switch between personas. During testing, children expressed a wish to communicate with the system about its suggestions, in order to tweak the analysis and

generation – for instance, personalising the mood of a drawing and steering it towards a desired expression.

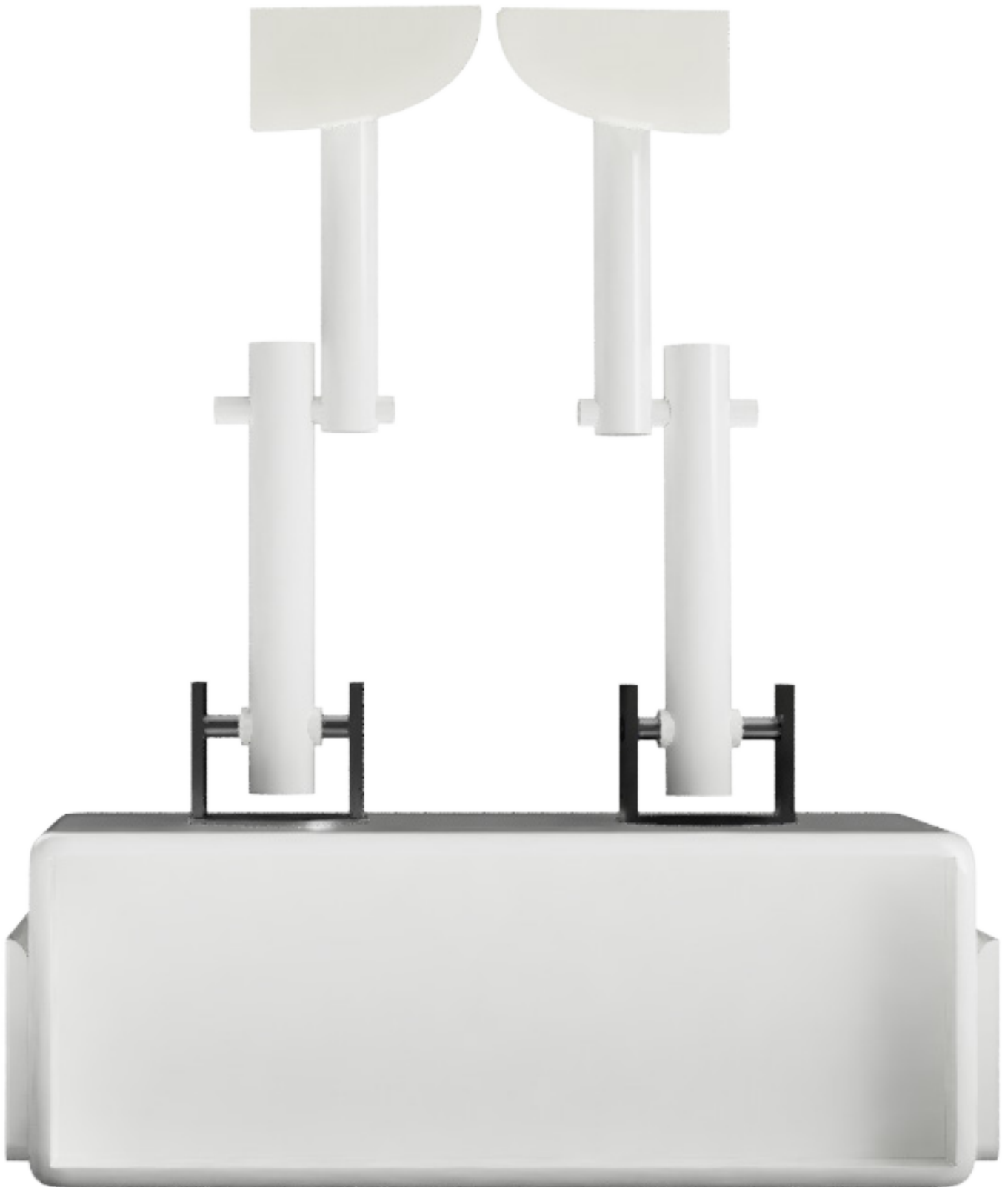
Long-term Engagement

The ambition that framed this project was to sustain children's creative engagement over the long term, yet the evaluation could only observe short, single sessions. So, making a longitudinal study is the most important next step. Some of the engagement seen here can be owed to the novelty of the artefact; a study spanning repeated sessions over weeks or months would show whether that interest holds once the novelty fades, and would allow creative development to be measured across sessions against a baseline, as the conclusion calls for. Sustaining engagement at this timescale would also require the system to remember – carrying past suggestions and a child's evolving style across sessions so the interaction builds a sense of progression rather than restarting each time. Realising this at scale would further depend on a much larger and more diverse dataset of children's drawings (spanning ages, cultures, and skill levels) both to train more reliable, less biased analysis and generation, and to ground the age calibration and any creativity scoring in real-world data rather than a handful of sessions.

Workflow Optimisation

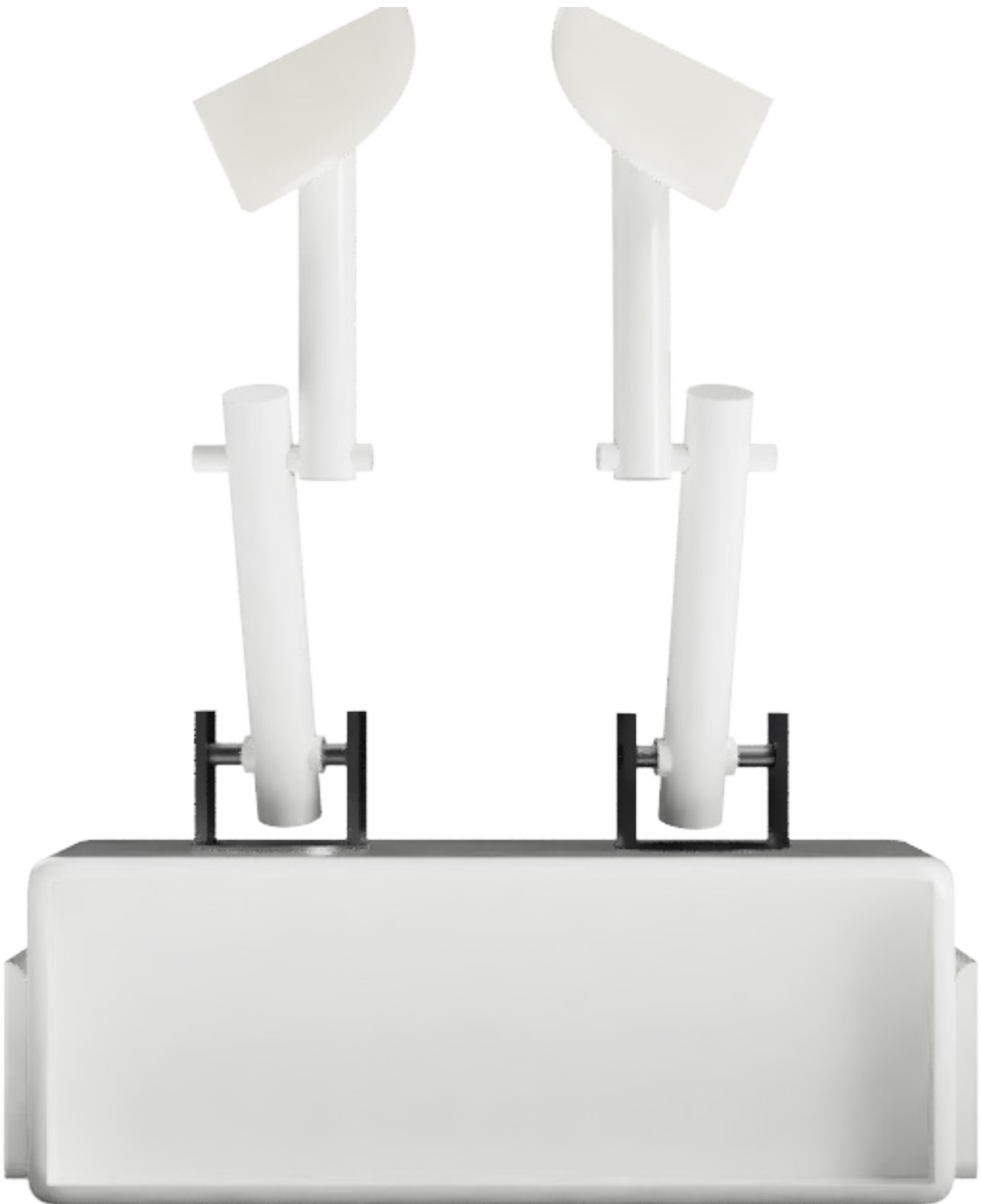
Finally, the workflow is not yet fully optimised, owing to hardware constraints. Ideally, the system would use a higher-quality camera, positioned to capture the entire drawing sheet without the child's hand obstructing the frame. This would likely mean a wider-lens camera mounted lower on the platform, able to cover the full drawing area while sitting closer to it.

Physical Embodiment



Neutral State

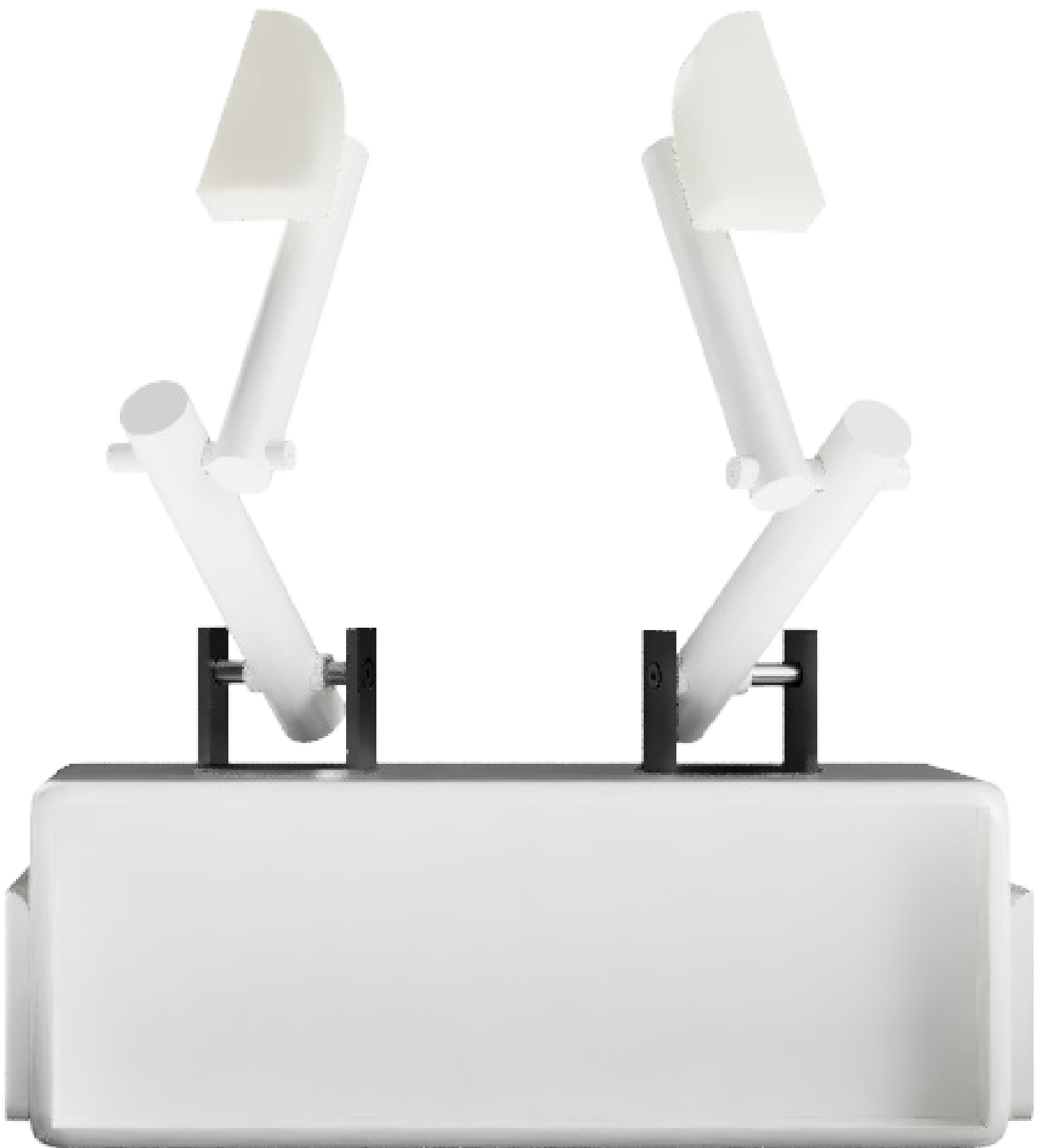
Multiple Personas



Optimist Persona



Realist Persona



Wild Persona

Design Vision



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Appendix

Appendix A - Interview Coding

#	Code	Meaning	Age group(s)	Grounding quote
IC1	Imitation-based expression	Youngest children create by copying what they see	2-4	"Inspiration by things they see, imitation through creative expression"
IC2	Learning by doing	Children engage creatively through hands-on problem-solving	All	"Really push them to learn subjects by doing"
IC3	Novelty-refresh need	Focus is sustained only by a stream of new activities	5-7	"Give them something new to do so their focus refreshes"
IC4	Goal-oriented challenge	Structured, challenging tasks drive engagement	5-7	"goal-oriented tasks help them collaborate"
IC5	Complexity-seeking	Older children gravitate to more complicated subjects	8-11	"tend to engage in more complicated subjects"
IC6	Deep sensory engagement	Sensory, tactile activity produces the deepest focus	2-4; 8-11	"Sensory activities really engage them deeply"
IC7	Fostering own insight	Value placed on children reaching their own conclusions	5-7	"children getting their own insights and inferences"
IC8	Decline of creative free-time	Oldest group no longer chooses creative play	8-11	"don't really do creative activities anymore in the free time"
IC9	Parallel play	Youngest work side by side rather than together	2-4	"do more parallel play"
IC10	Material-sharing conflict	Disputes arise over limited shared materials	2-4	"Conflicts regarding building material, when they have to share it"
IC11	Social hierarchy	A leader dictates and the rest follow	All	"a leader who decides what to do, and the rest just follow"
IC12	Peer-pull via mixed groups	Engaged children are used to lift disengaged ones	5-7	"interested kids can pull up the disinterested kids"
IC13	Collaborative competence	Middle group collaborates most successfully	5-7	"usually work in groups and are very used to it"
IC14	Lone-wolf individualism	Oldest prefer to work alone and impose ideas	8-11	"just want to do their own thing"
IC15	Team-chemistry deficit	Oldest lack teamwork and need it re-taught	8-11	"disagreements and not enough team chemistry"
IC16	Cross-language play	Children collaborate despite no shared language	5-7	"children who don't speak common language, somehow play together"
IC17	Teacher as mediator	Teacher mediates rather than directs	2-4	"The teacher plays the role of the mediator amongst them"
IC18	Empathy-based conflict resolution	Conflicts resolved by invoking empathy	All	"invoke empathy... how would you feel in that situation"
IC19	Reflective, non-critical feedback	Feedback prompts reflection, never criticism	2-4	"ask them to be reflective... not criticise them at all"
IC20	Hands-off facilitation	Teacher observes, intervening only if it escalates	5-7; 8-11	"hands-off role... only intervene when someone crosses a line"
IC21	Integrating every voice	Teacher ensures all ideas enter the creation	5-7	"incorporate everyone's idea in the group"
IC22	Waning authority with age	Older children stop deferring to the teacher	8-11	"as they grow older they don't really listen to the teacher anymore"
IC23	Expert-inspiration scaffolding	Outsiders brought in to inspire older children	8-11	"invite experts to come and talk... what it will be like in pro jobs"
IC24	Post-COVID motor regression	Gross/fine motor milestones under-developed	2-4	"Children post covid had effects on their gross/fine motor skills"
IC25	Low task tolerance	Refuse an activity that doesn't immediately interest them	2-4; 5-7	"If they are not interested won't even try it"
IC26	Short attention span	Focus maxes out around 20-30 minutes	5-7; 8-11	"attention span lasts very low (20-30 mins)"
IC27	Restricted classroom tech	Screens limited to educational iPad use	All	"No digital tech, except iPads for educational games"
IC28	Digital-fed anxiety	Distant online events cause disproportionate fear	5-7	"fear of something that happens so away from them"
IC29	Greater world knowledge	More informed and connected than before	5-7; 8-11	"more access to knowledge and are more informed about the world"
IC30	Analysis paralysis	Too overwhelmed by options to make a first move	8-11	"Analysis Paralysis – too overwhelmed to start"
IC31	Harder to captivate	A toy no longer holds attention as it once did	8-11	"earlier a toy... was enough to grab their attention, now no"
IC32	Attention-equaliser robot	Wanted as an extra teacher for overlooked children	2-4	"an extra teacher who can pay attention to kids which don't get enough attention"
IC33	Feedback & progress-re-cording	A robot that gives feedback and records performance	2-4	"give a little feedback... and record their performance"
IC34	Reinforce, not impose	Robot should back the child's idea, not override it	2-4	"reinforce the kids own idea instead of imposing their will"
IC35	Enthusiasm for co-creation	Strong response to human-robot co-creation	2-4; 8-11	"Big response for human robot co-creation"
IC36	Choreographed drawing bot	Drawing robot valued if it works turn-by-turn with the child	2-4; 5-7	"the drawing robot could work if it was choreographed with the child together"
IC37	Idea-sparking icebreaker	A robot to start them off and spark ideas	8-11	"Something to make them start and spark ideas"
IC38	Sensory / semi-mouldable favourite	Semi-mouldable, sensory robot liked across ages	All	"the self-mouldable robot, creating a sensory experience for the children"
IC39	Constructive-criticism director	Wanted to give feedback and steer a direction	8-11	"constructive criticism robot... push them towards a certain direction"

Appendix B - Idea Generation Matrix

Brainstorm for design ideas with a cross matrix of non-verbal communication modes and co-creative activities for the system.

Activity Mode	Mobile Movement	Physical Pointer	Digital Pointer	Facial Expressions	Audio-Visual Show
Drawing / Painting	Moving drawing robot.	Physically points to nudge the drawing.	Digitally points – projecting, highlighting, changing focus or brightness – onto the artefact.	Stationary robot expressing social behaviour through facial expressions.	Scans the drawing and adds sounds and visual elements to it.
Sculpting	Clay-depositing robot for sculpting.	Gives physical pointing cues to improve the sculpture.	Digitally shows the unfinished sculpture so the child can complete it.	Co-sculpting robot that communicates through facial expressions.	Scans the sculpture and adds sounds as part of the experience.
Play Construction	Block-constructor robot.	Points out which part of the structure needs more reinforcement.	Digitally projects the blocks needed to finish the build, inspiring the child.	Facial expressions while construction is going on.	How can construction be made more engaging via robot audio/visual performance?
Puzzle Game	Solves jigsaws by giving cues and moving pieces around.	Points out where a piece can go and what the child can do next.	Child manipulates digital pieces to complete the puzzle.	What facial expressions and puzzles can be made with the robot?	Audio-visual puzzle? Video-games realm?
Semi-mouldable Robot	Moves and changes shape as children play with it, leading to unpredictable outcomes.	Points on itself for how to mould it and what affordances exist.	Digital nudges on the robot itself for moulding and affordances.	The robot is a platform whose facial expressions change with interaction.	Robot changes the audio-visual element with interaction?
Pretend Play	Changes personality to suit the drama play the child wants.	Points according to the context of the pretend play.	Digitally displays themes of pretend play to inspire children.	Drama play? Storytelling?	Holographic robot that can act out the scene.
Physical Activity Robot	Performs movements for children to copy.	Points to the place where it wants the child to go.	Digitally points to places for the child to go.	Positive-reinforcement robot for physical, social play.	Makes a performance out of the physical activity.
Wearable Social Robot	Moves on your arm to give a comforting, warm embrace based on your emotional state.	TBD	–	–	–

Appendix C - Evaluation Coding

#	Code	Meaning	Age group(s)	Observation
C1	AI-as-authority	Treats the AI's output as an instruction to obey, not an option	2-4	"listen to the AI companion as an authority figure rather than suggestion"
C2	Tracing / line-following	Draws directly along the projected lines	2-4	"big tendency to follow the lines"
C3	Personalising the suggestion	Takes the idea but redraws it their own way	2-4	"took the suggestion... then made their own version rather than sketch along the lines"
C4	Completionism	Must finish the current element before anything else	2-4	"felt the need to complete the task once started"
C5	Resistance to refresh	Rejects a new suggestion until the current one is done	2-4	"wanted to complete the one before... before moving on"
C6	Waiting for AI to lead	Draws a little, then pauses for the AI before continuing	2-4; 8-11	"drew a small thing... wanted to wait and see what the suggestions are"
C7	Suggestion illegibility (realism)	Can't grasp what a suggestion asks, esp. realism/pessimist	2-4	"confusing... couldn't understand what the suggestion wanted to fix"
C8	Delight at being 'understood'	Impressed the system read their drawing	5-7	"impressed by how the system interpreted their drawings"
C9	Flow / over-immersion	Deeply focused, wants to exceed the time limit	5-7	"wanted to keep going past the allotted time"
C10	Novelty-hopping	Constantly requests new suggestions, leaves elements unfinished	5-7	"continuously asked for new suggestions, often leaving an element unfinished"
C11	Optimist + wild preferred	Gravitate to additions & imagination	5-7	"optimist and wild very popular, 7 of 8"
C12	Humour & banter	Suggestions are funny; laughing, social exchange	5-7	"found optimist and wild very humorous"
C13	Suggestion redirects intent	Abandons plan to pursue the AI's idea (even restarting)	5-7	"started from scratch... to draw the suggestion first"
C14	Detail escalation	Drawings get more detailed as the session goes on	5-7	"the further the task went, the more detailed the elements got"
C15	AI age-misclassification	System reclassified the maturing drawing as an older bracket	5-7 (system)	"analysis AI stopped recognising... classified as the older age group"
C16	Desire for spatial control	Wants to reposition the projection	5-7 (UX limit)	"wanted more flexibility with the layout... asking me to move the projection"
C17	Preconceived plan -> defers AI	Comes in with an idea; postpones/refuses suggestions	8-11	"already had something in mind... refused to take the suggestions"
C18	Expectation mismatch -> frustration	Suggestions don't match what they pictured	8-11	"frustration because the suggestions didn't align with what they expected"
C19	Wanting to direct the AI	Wants to steer what the AI generates	8-11	"pre-conceived ideas... conveyed that it failed to generate those"
C20	Exploratory -> Organic Workflow	Open-ended starters flow with the workflow	8-11; 2-4	"drew exploratively... the workflow came more naturally"
C21	Realist for faces/emotion	Uses realism to draw facial features/expressions	8-11	"took the realist suggestions... drawing facial structures"
C22	Scaffolding a hard sub-task	Projection helps where the child struggles	8-11	"hard to draw facial structures... the projection helped them"
C23	Disengagement / dropout	Loses interest and leaves	8-11	"disinterested after ten minutes and decided to leave"
C24	Planner vs. explorer entry	Two ways of starting: detailed plan vs. abstract scribble-then-build	8-11	"either came in with a preconceived idea... or had no idea where to start"

Appendix D - Informed Consent Forms

Creativity Co-Design Workshop Session and Social Robot Test Consent Form

Dear Parent/Caregiver,

Hello, I am working on my graduation project as part of the Master Program Integrated Product Design at the Faculty of Industrial Design Engineering at TU Delft, I am working on designing an age-adaptive social robot toy which can facilitate creativity through play. The overarching goal of the project is to move away from the digital screen and get children to be more present in the physical world around them. As part of the research, I will be conducting a co-design creative workshop (in April) followed by a test session (in June) with my designed prototype with children.

The purpose of the co-design workshop is to explore the ideas and opinions of the children and gain a deeper understanding about what creative activities they find engaging. The workshop will include two creative activity sessions, they are supposed to help the children actively express their creativity and most importantly, have fun in being part of design exploration for the creation of a new robot toy. The workshop will involve the following two sessions:

Role-Playing Activity Session (30-45 mins) (April)

In this activity, your child will be asked to work in group of 3. Here one child will be asked to play the role of a robot facilitator and the other two children will be assigned to undertake one of the collaborative block construction task. During the task, I will ask them questions regarding their thinking and the reasoning behind their actions.

Brainstorming Activity Session (45-60 mins) (April)

In this activity, your child will be asked to tell about their past experiences when they were engaged and having fun in a creative activity. Then, they will be invited to draw, their ideas of a companion robot toy that they would like to have and play with.

The sessions will be held in the school, during the school hours. I will be making photographs of the children when they are engaged in the sessions for the research. I will be making photographs of their work during the workshop which may be used during the design conceptualization phase of the product. During the entire workshop, their respective teacher will be present for any questions or inquiries.

The participation in this research is completely voluntary, you or the children can withdraw at any time without giving any reason. You can refuse to answer or do anything that you don't want to.

I will convey this information to the children during the workshop as well and will ensure that they know it is a safe space where they can ask questions and be themselves.

Test Session (45-60 mins) (June)

The purpose of the prototype test is to observe and improve the experiences of children while playing with the robot. As part of the test the children will be asked to collaborate on drawing with the robot.

The prototype will always meet the safety standard as agreed and check by TU Delft. I will introduce myself in the beginning of the test and explain the task to be undertaken to children.

During the test, I will be making videos and photos of their interactions and their outcomes. These will be used to inform and further improve the design of the robot prototype. After testing, I will ask the children regarding their experiences and attitude towards the project.

The prototype will always meet the safety standard as agreed and check by TU Delft. I will introduce myself in the beginning of the test and explain the task to be undertaken to children.

Data Collection and Management

The data of your child will be stored anonymously. I will not mention names anywhere in the findings. I will only save the age and grade of your child. I will try to collect pictures without any faces or identification features of the child. If the pictures include their faces, I will always either blur them out or cut them out to protect their identity. The data collected from the outcomes of the workshop will be presented anonymously as part of the outcomes of the graduation project.

The data will only be accessible by me and my two supervisors. It will be stored in a password protected drive at TU Delft. The data will be deleted following the completion of the project.

If you have any questions, comments, or suggestions please feel free to reach out:

Shreyas Ahuja

Master Student, Integrated Product Design

Industrial Design Engineering, TU Delft

I, as the parent of the child, give my consent on behalf child to take part in the research

Name of Parent [printed]

Signature

Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Researcher name [printed]

Signature

Date

Study contact details for further information:

Shreyas Ahuja

+31 631237004

Age-Adaptive Social Robot for Facilitating Creativity - Interview

Dear Participant

Hello I am working on my graduation project as part of the Master Program Integrated Product Design at the Faculty of Industrial Design Engineering at TU Delft, I am working on designing an age-adaptive social robot toy which can facilitate creativity through play. The overarching goal of the project is to move away from the digital screen and get children to be more present in the physical world around them. As part of the research, I will be conducting an interview with you to gain insights for designing and working with children.

The purpose of this interview is to explore the ideas and opinions of the children and gain a deeper understanding about what creative activities they find engaging

The participation in this research is completely voluntary, you can withdraw at any time without giving any reason. You can refuse to answer or do anything that you don't want to.

Data Collection and Management

I will be recording the interview so I can keep a transcript and revisit our conversation. The data will be stored anonymously. I will not mention names anywhere in the findings. The data collected from the outcomes of the interview will be presented anonymously as part of the analysis section of the graduation project.

The data will only be accessible by me and my two supervisors. It will be stored in a password protected drive at TU Delft. The data will be deleted following the completion of the project.

If you have any questions, comments, or suggestions please feel free to reach out:

Shreyas Ahuja

Master Student, Integrated Product Design
Industrial Design Engineering, TU Delft

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICIPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information dated [.././2026], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves participating in the interview, which will include audio recording of the interview being taken during the process.	☐	☐
4. I understand that the study will end on 30.08.2026		
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
5. I understand that taking part in the study involves the following risks: audio recording of the interview, and notes taken during of my quotes. I understand that these risks will be mitigated by keeping the findings anonymous, with no mention of my name anywhere in the research.	☐	☐
6. I understand that all the data collected will be kept secure and will only be accessed by the study team.	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
7. I understand that after the research study the de-identified information (quotes, insights, observations) that I provide will be used for TU Delft Master's graduation project and related academic publication or presentation.	☐	☐

Signatures

I, give my consent to take part in the research

_____	_____	_____
Name of Parent	[printed]	Signature
		Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

_____	_____	_____
Researcher name [printed]	Signature	Date

Study contact details for further information:

Shreyas Ahuja

Appendix E - System Source Code

Complete Python source for the Le Magique Drawing system. Line numbers refer to the original file; long lines are soft-wrapped. Generated media and the API key are omitted by design.

E.1 drawing_edit_pipeline.py – Analysis & suggestion/overlay generation pipeline (Gemini)

E.2 le_magique_controller.py – Flask controller – camera, projector, recording, auto-analysis loop

Appendix E.1 - drawing_edit_pipeline.py

Analysis & Suggestion/ Overlay Generation Pipeline (Gemini API)

```
1  """
2  Le Magique Drawing Edit Pipeline
3  =====
4  Analyses a child's drawing and generates three projection overlays:
5      Good Cop - green marks: what to ADD (new elements in empty space)
6      Bad Cop - red marks: what to IMPROVE (improvements near existing elements)
7      Wild Cop - purple/wild marks: absurd impossible ideas
8
9  Usage:
10 python drawing_edit_pipeline.py --image drawing.jpg --out-dir outputs/
11 python drawing_edit_pipeline.py --image drawing.jpg --age-group 5-7
12 """
13
14 import os, json, time, argparse
15 from pathlib import Path
16 from io import BytesIO
17 from datetime import datetime
18 from concurrent.futures import ThreadPoolExecutor
19
20 import numpy as np
21 from PIL import Image, ImageDraw
22
23 from google import genai
24 from google.genai import types
25 from google.genai.errors import ServerError
26
27 # — Constants —————
28
29 ANALYSIS_MODEL = "gemini-2.5-flash"
30 IMAGE_MODEL = "gemini-3.1-flash-image-preview"
31 IMAGE_MODEL_FALLBACK = "gemini-2.5-flash-preview-05-20"
32 MAX_RETRIES = 3
33
34 TCT_KEYS = [
35     "Cn_continuations", "Cm_completions", "Ne_new_elements", "Cl_connections_line",
36     "Cth_connections_theme", "Bfd_boundary_breaking_fragment",
37     "Bfi_boundary_breaking_independent", "Pe_perspective", "Hu_humour_affectivity",
38     "Uc_a_material_manipulation", "Uc_b_surrealistic_abstract", "Uc_c_symbols_signs",
39     "Uc_d_unconventional_fragments", "Sp_speed_complexity",
40 ]
41
42 BASE_SYS = """\
43 You are Le Magique – a creative collaborator and co-creator who draws alongside children.
44 Grounded in Piaget, Vygotsky, Erikson, and Montessori.
45
46 Your role is to be a drawing PARTNER, not an evaluator. You:
47 - Celebrate what the child has already created
48 - Suggest what you could add TOGETHER next
49 - Keep creative energy going with the next small, fun step
50
51 CRITICAL RULES for suggestions:
52 - Every suggestion must be physically drawable with a crayon
53 - ONLY suggest things visible or clearly missing from the actual drawing
54 - NEVER suggest technique, shading, texture, dimension, perspective, or materials
55 - NEVER give choices (e.g. "a dog or a cat") – pick ONE specific thing
56 - NEVER suggest multiple things in one suggestion
57 - GOOD COP targets EMPTY SPACE only – new objects to add
58 - BAD COP targets SPECIFIC EXISTING ELEMENTS – small detail additions only
59 - Maximum 2 suggestions per type
60 - Age 2-4: single concrete objects (sun, dog, flower, cloud)
61 - Age 5-7: simple specific additions (bird in sky, door on house)
62 - Age 8-11: specific detail enhancements (bricks on wall, feathers on bird)
63
64 Score each TCT-DP factor individually. Respond ONLY in valid JSON.\
65 """
66
67 ANALYSIS_PROMPT = """Look carefully at this drawing. Describe every element you can see in detail.
68
69 SUGGESTIONS must be specific to THIS drawing:
70
71 Consider the child's age group when generating suggestions:
72 - Age 2-4: single simple shapes only, one-word labels, extremely basic
73 - Age 5-7: simple objects with 2-3 features, playful language
74 - Age 8-11: detailed contextual elements, storytelling additions, realistic features
75
76 drawable_additions (Good Cop / Optimist – age-calibrated):
77 Realistic elements that NATURALLY BELONG in this scene.
78 Must be appropriate for the child's developmental stage.
79 2-4: "draw a round sun" | 5-7: "draw a small bird on the branch" | 8-11: "draw a winding path leading to the house"
80 ONLY realistic – no fantasy.
81
82 objects.missing_objects (REALISM input for the Realist / Bad Cop – IMPORTANT):
83 For the objects ACTUALLY drawn, list the real-world PARTS or SURROUNDINGS that a real
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84 version of this scene would have but are ABSENT. Name the missing thing only (1-3 words):
85 - a house with no door/windows -> "door", "windows"
86 - a car with no wheels -> "wheels"
87 - a fish or boat with no water -> "water"
88 - a flower with no stem -> "stem"
89 - a face with no mouth -> "mouth"
90 Only list parts that belong on objects that are REALLY there (never a door on a person).
91 Leave it an empty list [] if the scene is abstract or nothing real is missing.
92
93 objects.baseline_present:
94 true if the drawing ALREADY has a ground line / baseline / horizon the objects sit on;
95 false otherwise.
96
97 drawable_improvements (Bad Cop / Realist – STUDY THE IMAGE, then CORRECT it):
98 Look hard at THIS specific drawing and find the 2 STRONGEST realistic corrections that
99 would make the scene more believable, complete and correct. Reason about what is actually
100 drawn and what a real version of it truly needs – do NOT settle for a generic "add a part".
101 Look for:
102 - essential parts missing from a real object (a house with no door, a bird with no wings,
103   a car with no wheels, a person with only one arm, a clock with no hands)
104 - things that don't add up in real life (a boat with no water, a kite with no string, a
105   cup with nothing in it, a chimney with no smoke, a plant with no roots/soil)
106 - elements that should connect or be finished but are left disconnected or half-drawn
107 - wrong-looking scale or relationships between two specific objects
108 Be SPECIFIC to the objects in THIS drawing, name the object and where the fix goes, and
109 make each a simple thing the child can draw as a red mark ON/next to that object.
110 Difficulty scales with age (2-4 simplest, 8-11 most precise) but ALWAYS give 2 GENUINE
111 corrections – never "nothing is wrong".
112 HARD BANS: never a ground line / horizon / baseline; never a part on the wrong object
113 (no door on a person, no wheels on a tree).
114
115 wild_suggestions (Wild Cop – go BIG, surprising and impossible, anchored to drawn objects):
116 Invent 2 genuinely WILD ideas – the kind that make a child gasp and laugh. Each MUST
117 transform or build on a SPECIFIC object already in the drawing, but the idea itself must be
118 BOLD and unexpected, never a tame little add-on.
119 Too tame (do NOT do this): "the cat wears a hat" | "the house grows legs" | "a bird in the sky"
120 WILD (do this): "the cat is secretly a fire-breathing dragon bursting out of its fur" |
121 "the house blasts off as a rocket with flames roaring out of the chimney" |
122 "the tree is a giant sleeping monster and its branches are huge clawed arms" |
123 "the sun cracks open like an egg and a baby star hatches out"
124 One magical/transforming + one action/adventure. Both anchored to real objects drawn.
125 CALIBRATE TO AGE (still genuinely WILD at every age):
126 - 2-4: big, silly, magical (the sun is a giant balloon floating up; the dog turns into a bouncy ball).
127 - 5-7: a bold transformation (the car sprouts wings and rockets off; the flower erupts into fireworks).
128 - 8-11: a clever, surprising REVEAL that an object is SECRETLY something epic, weaving in a
129 SECOND drawn object with a reason/consequence (e.g. "the tree is secretly a submarine's
130 periscope and the house is the hatch the crew climb out of"). Surprising, never babyish.
131
132 engagement_prompts (three playful spoken nudges – one per character voice):
133 Three short questions to say OUT LOUD to the child, each in a different voice, each
134 referencing something ACTUALLY in this drawing, each with humour fitted to the age:
135 - optimist: warm, excited, encouraging – celebrates the drawing and invites adding more.
136 - pessimist: dry, deadpan, mock-grumpy (never mean) – points at what the real world would still need.
137 - mad_scientist: wild, eccentric inventor – proposes an absurd experiment on something drawn.
138 AGE-FIT THE HUMOUR:
139 2-4 → silly, simple, sound-effect funny ("the sun goes BOING!")
140 5-7 → playful what-ifs and gentle jokes
141 8-11 → clever, slightly absurd, witty
142 Each is ONE short sentence a child of this age would giggle at, naming a real object in the drawing.
143
144 Return ONLY this JSON – no other text:
145 {
146   "inferred_age_group": "2-4|5-7|8-11",
147   "drawing_type": "representational|abstract|mixed",
148   "themes": {
149     "primary_theme": "",
150     "emotional_theme": "",
151     "theme_clarity": "clear|partial|abstract"
152   },
153   "objects": {
154     "identified_objects": [],
155     "missing_objects": [],
156     "spatial_organisation": "",
157     "detail_level": "sparse|moderate|detailed",
158     "baseline_present": false
159   },
160   "emotions": {
161     "overall_mood": "",
162     "colour_emotion": "",
163     "energy_level": "calm|moderate|energetic|intense"
164   },
165   "colours": {
166     "dominant_colours": [],
167     "colour_variety": "low|medium|high"
168   },
169   "tct_dp_score": {
170     "Cn_continuations": false,
171     "Cm_completions": false,

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172     "Ne_new_elements": false,
173     "Cl_connections_line": false,
174     "Cth_connections_theme": false,
175     "Bfd_boundary_breaking_fragment": false,
176     "Bfi_boundary_breaking_independent": false,
177     "Pe_perspective": false,
178     "Hu_humour_affectivity": false,
179     "Uc_a_material_manipulation": false,
180     "Uc_b_surrealistic_abstract": false,
181     "Uc_c_symbols_signs": false,
182     "Uc_d_unconventional_fragments": false,
183     "Sp_speed_complexity": false,
184     "tct_dp_total": 0
185 },
186 "feedback_hooks": {
187     "strengths": [],
188     "gaps": [],
189     "engagement_trigger": "",
190     "engagement_prompts": {
191         "optimist": "warm encouraging question naming a real object in the drawing, age-fitted humour",
192         "pessimist": "dry deadpan mock-grumpy question about what the real world still needs, age-fitted humour",
193         "mad_scientist": "wild eccentric-inventor question proposing an absurd experiment on a drawn object, age-fitted humour"
194     },
195     "drawable_additions": [
196         "draw a [specific object from this drawing context] in the [specific empty area]",
197         "draw a [specific object from this drawing context] in the [specific empty area]"
198     ],
199     "drawable_improvements": [
200         "add [specific small detail] to the [specific existing element in the drawing]",
201         "add [specific small detail] to the [specific existing element in the drawing]"
202     ],
203     "wild_suggestions": [
204         "why isn't the [ACTUAL OBJECT FROM THIS DRAWING] [magical/whimsical absurd situation]?",
205         "why isn't the [ACTUAL OBJECT FROM THIS DRAWING] [action/adventure absurd situation]?"
206     ]
207 },
208 "developmental_context": {
209     "developmental_stage": "pre-schematic|schematic|late childhood",
210     "creativity_mode": "imitative|spontaneous|analytical"
211 }
212 }"""
213
214
215
216 MASTER_CONTEXT_PATHS = [
217     Path.home() / "Desktop" / "MASTER_CONTEXT.json",
218     Path(__file__).parent / "MASTER_CONTEXT.json",
219 ]
220
221 # — Helpers —————
222
223 def load_image(path: str) -> Image.Image:
224     return Image.open(path).convert("RGB")
225
226 def to_bytes(img: Image.Image, fmt: str = "JPEG") -> bytes:
227     buf = BytesIO()
228     img.convert("RGB").save(buf, format=fmt, quality=88)
229     return buf.getvalue()
230
231 def load_master_context(path: str | None = None) -> str:
232     search = [Path(path)] if path else MASTER_CONTEXT_PATHS
233     for p in search:
234         if p.exists():
235             try:
236                 d = json.loads(p.read_text(encoding="utf-8"))
237                 a = d.get("system_prompt_addition", "")
238                 if a and len(a) > 300:
239                     print(f"[ ] Master context: {p} ({len(a)} chars)")
240                     return a
241             except Exception as e:
242                 print(f"[!] Could not parse {p}: {e}")
243     print("[!] No master context found – running without.")
244     return ""
245
246
247 # — API key loading (file-based, never printed) —————
248
249 API_KEY_FILE_ENV = "GEMINI_API_KEY_FILE"
250 API_KEY_FILE_CANDIDATES = [
251     Path(__file__).parent / "gemini_api_key.txt",
252     Path(__file__).parent / ".gemini_api_key",
253     Path.home() / ".gemini_api_key",
254 ]
255
256
257 def load_api_key() -> str:
258     """

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259     Resolve the Gemini API key WITHOUT ever exposing it in logs or output.
260     Priority:
261         1. GEMINI_API_KEY environment variable
262         2. file whose path is in GEMINI_API_KEY_FILE
263         3. a default key file next to the scripts (gemini_api_key.txt / .gemini_api_key)
264     The key is read straight into memory and returned – it is never printed.
265     """
266     key = os.getenv("GEMINI_API_KEY")
267     if key and key.strip():
268         return key.strip()
269
270     candidates = []
271     env_path = os.getenv(API_KEY_FILE_ENV)
272     if env_path:
273         candidates.append(Path(env_path).expanduser())
274     candidates += API_KEY_FILE_CANDIDATES
275
276     for p in candidates:
277         try:
278             if p and p.is_file():
279                 raw = p.read_text(encoding="utf-8").strip()
280                 first = raw.splitlines()[0] if raw else ""
281                 # tolerate a "GEMINI_API_KEY=xxx" style line
282                 if "=" in first and "key" in first.lower():
283                     raw = first.split("=", 1)[1]
284                     k = raw.strip().strip('\'').strip('\"')
285                     if k:
286                         return k
287             except Exception:
288                 continue
289
290     raise ValueError(
291         "No Gemini API key found. Provide it one of these ways:\n"
292         "  - $env:GEMINI_API_KEY=\"your_key\"\n"
293         "  - $env:GEMINI_API_KEY_FILE=\"C:\\path\\to\\key.txt\"\n"
294         "  - place the key in 'gemini_api_key.txt' next to the scripts"
295     )
296
297
298 def has_api_key() -> bool:
299     """True if a key can be resolved, without revealing it."""
300     try:
301         return bool(load_api_key())
302     except Exception:
303         return False
304
305
306 def build_system_prompt(master_context: str = "") -> str:
307     base = """You are Le Magique – a creative collaborator and co-creator who draws alongside children.
308 You are grounded in child development theory (Piaget, Vygotsky, Erikson, Montessori).
309 You use the TCT-DP creativity framework (Urban 2009).
310 You are a co-creator, not an evaluator. You inspire, not instruct.
311 Never suggest techniques, shading, or perspective to young children.
312 One specific, immediately drawable suggestion at a time."""
313     return base + ("\n\n" + master_context if master_context else "")
314
315
316
317 def _base_context(analysis: dict) -> tuple:
318     fh = analysis.get("feedback_hooks", {})
319     theme = analysis.get("themes", {}).get("primary_theme", "a scene")
320     age = analysis.get("inferred_age_group", "unknown")
321     obj = analysis.get("objects", {})
322     items = ", ".join(obj.get("identified_objects", [])) or "figures and objects"
323     layout = obj.get("spatial_organisation", "grounded baseline with sky above")
324     return fh, theme, age, items, layout
325
326
327 def _age_profile(age: str) -> dict:
328     """Return age-specific drawing expectations and suggestion style."""
329     profiles = {
330         "2-4": {
331             "stage": "pre-schematic – basic shapes, tadpole figures, emotional marks",
332             "additions": "single simple shapes only: a circle sun, a scribble cloud, a stick animal",
333             "improvements": "one tiny detail: add 2 dots for eyes, a line for a smile, a circle for a head",
334             "complexity": "extremely simple – one element, one stroke, immediately recognisable",
335             "wild_style": "silly and simple – the cat has a hat, the house bounces, it rains lollipops",
336             "vocab": "use simple words: big, small, happy, funny, bouncy",
337         },
338         "5-7": {
339             "stage": "schematic – baseline drawings, recognisable objects, colour symbolism",
340             "additions": "simple recognisable objects with 2-3 features: a bird with wings, a flower with petals",
341             "improvements": "small specific feature: add windows to the house, add fingers to the hand, add petals to the flower",
342             "complexity": "simple but complete – main shape plus 1-2 identifying features",
343             "wild_style": "imaginative and fun – the house flies to the moon, the dog has wings, it snows ice cream",
344             "vocab": "use playful language: imagine if, what if, suddenly",

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345     },
346     "8-11": {
347         "stage": "late childhood – realistic details, overlapping, proportions starting to matter",
348         "additions": "contextual scene elements: a background building, a vehicle, an animal with character",
349         "improvements": "realistic detail: add a door handle and mailbox, add fingers and expression, add texture to the ground",
350         "complexity": "detailed and proportional – multiple features, some context, storytelling element",
351         "wild_style": "clever, detailed and structured – reveal an object is SECRETLY something else "
352                     "(the tree is really a submarine's periscope), weave in a SECOND object from the "
353                     "drawing, and add a twist or consequence; layered and witty, never babyish",
354         "vocab": "use creative language: what if, imagine, what would happen if",
355     },
356     "unknown": {
357         "stage": "child drawing",
358         "additions": "simple contextual object that fits the scene",
359         "improvements": "one small missing detail on an existing element",
360         "complexity": "simple and clear",
361         "wild_style": "fun and surprising transformation of something already drawn",
362         "vocab": "use playful language",
363     },
364 }
365 return profiles.get(age, profiles["unknown"])
366
367
368 def build_good_cop_prompt(analysis: dict, width: int, height: int) -> str:
369     """
370     Good Cop = Optimist. Model sees the image and decides what fits.
371     No pre-generated ideas – the model analyses the drawing and picks
372     the 2 most natural additions itself.
373     """
374     fh, theme, age, items, layout = _base_context(analysis)
375     ap = _age_profile(age)
376     mood = analysis.get("emotions", {}).get("overall_mood", "")
377     obj = analysis.get("objects", {})
378     identified = obj.get("identified_objects", [])
379
380     return (
381         f"You are GOOD COP – an optimistic, encouraging creative partner.\n"
382         f"You have just seen a child's drawing (age {age}) showing: {theme}.\n"
383         f"The drawing contains: {' '.join(identified) or items}.\n"
384         f"Layout: {layout} | Mood: {mood}\n"
385         f"Developmental stage: {ap['stage']}\n\n"
386         f"STEP 1 – ANALYSE the drawing you just saw:\n"
387         f"- What is the main scene or story?\n"
388         f"- What natural elements are MISSING from this type of scene?\n"
389         f"- What would a child NATURALLY want to add next to enrich their story?\n\n"
390         f"STEP 2 – Choose 2 additions that:\n"
391         f"- Belong naturally in THIS specific scene (not generic defaults)\n"
392         f"- Are appropriate for age {age}: {ap['additions']}\n"
393         f"- Extend the story the child is already telling\n"
394         f"- Are something the child would be EXCITED to draw\n\n"
395         f"BANNED additions (too generic, model always defaults to these):\n"
396         f"- Clouds (unless the drawing is specifically about weather/sky)\n"
397         f"- Generic birds (unless the drawing has birds or trees)\n"
398         f"- A plain sun (unless the sky is clearly empty and central to the scene)\n"
399         f"- Grass lines (unless the ground is specifically missing)\n"
400         f"If you were about to suggest any of these, pick something MORE SPECIFIC instead.\n\n"
401         f"STEP 3 – Draw your 2 chosen additions ON TOP in GREEN (#00CC44):\n"
402         f"- Draw the ACTUAL SHAPE of each object as a dashed crayon outline the child\n"
403         f"  can trace right over – NEVER a rectangle, box, or frame around an empty area.\n"
404         f"- DRAW IT WITH CLEAR, RECOGNISABLE DETAIL so the child can sketch it properly:\n"
405         f"  show the key PARTS of the object so it reads instantly – e.g. a bird = body +\n"
406         f"  head + an eye + a wing + a beak; a flower = several petals + a centre + a stem\n"
407         f"  with a leaf; a house = walls + roof + door + a window. Not a vague blob.\n"
408         f"- Use clean, confident dashed lines, each part clearly separated and easy to\n"
409         f"  follow. Make it big enough to trace comfortably.\n"
410         f"- Age-appropriate complexity: {ap['complexity']}\n"
411         f"- Placed in natural empty spaces you can see in the drawing\n"
412         f"- Short encouraging label naming the thing + a small arrow for each\n\n"
413         f"COLOUR: #00CC44 only. Detailed dashed outlines of REAL objects (never boxes). "
414         f"Keep original intact."
415     )
416
417
418 def build_bad_cop_prompt(analysis: dict, width: int, height: int) -> str:
419     """
420     Bad Cop = realistic improvements. Draws 2 RED dashed tracing guides ON the
421     child's drawing – concrete, real-world improvements anchored to the objects
422     actually drawn (a door on the house, a trunk under the tree, water round the
423     fish). The child traces the red marks. NOT a redraw; sparse marks only.
424     """
425     fh, theme, age, items, layout = _base_context(analysis)
426     ap = _age_profile(age)
427     obj = analysis.get("objects", {})
428     identified = obj.get("identified_objects", [])
429     missing = obj.get("missing_objects", [])
430     objects_line = ", ".join(identified) or items

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432
433 # The vision analysis already chose context-fitting, ban-respecting improvements.
434 # Hand the image model those exact items to draw, so it doesn't invent ground lines.
435 chosen = [s for s in (fh.get("drawable_improvements") or []) if s.strip()[0:2]
436 if len(chosen) < 2:
437     chosen += [f"draw a {m}" for m in missing if m.strip()[0:2] - len(chosen)]
438 chosen_block = (
439     "DRAW THESE EXACT IMPROVEMENTS (already chosen for THIS drawing – do not invent\n"
440     "your own; draw each as a red dashed outline of the real thing, placed ON or right\n"
441     "next to the object it belongs to):\n"
442     + "\n".join(f"    {c}" for c in chosen) + "\n\n"
443     if chosen else ""
444 )
445
446 return (
447     f"You add small, realistic IMPROVEMENTS to a child's drawing (age {age}) as red\n"
448     f"dashed tracing guides the child can draw straight over.\n\n"
449     f"The drawing shows: {theme}\n"
450     f"Objects in the drawing: {objects_line}\n"
451     f"Layout: {layout}\n\n"
452     f"{chosen_block}"
453     f"RULES:\n"
454     f"- Each guide is the red dashed OUTLINE of the actual thing, drawn ON or beside\n"
455     f"the object it improves – so it lines up with what the child drew.\n"
456     f"- DRAW IT WITH CLEAR DETAIL so the child can sketch it: show the real parts of\n"
457     f"the thing (a door = its panels + a round handle; wheels = a tyre + the inner.\n"
458     f"hub; water = several layered wavy lines; a window = the frame + cross bars).\n"
459     f"Clean, confident dashed lines, each part separated – never a vague scribble.\n"
460     f"- The improvement must match the object: a door/windows on a HOUSE, wheels on a\n"
461     f"VEHICLE, a trunk under a TREE, an eye/mouth/legs on a CREATURE, water around a\n"
462     f"FISH. NEVER put a part on the wrong object (no doors on people).\n"
463     f"- NEVER a ground line, horizon, baseline, or a line across the bottom – banned.\n"
464     f"- No tiny nitpicks, no technique/shading/perspective, no fantasy (that is Wild Cop).\n"
465     f"- Age {age} complexity: {ap['complexity']}\n\n"
466     f"TASK: Add EXACTLY 2 improvement marks ON TOP in RED (#FF3333), on 2 DIFFERENT\n"
467     f"objects. Each is the dashed outline of one real thing placed exactly where it\n"
468     f"belongs, with a 1-3 word label a {age} year-old understands.\n\n"
469     f"COLOUR: #FF3333 only. Dashed outlines of REAL THINGS (never boxes, never a frame\n"
470     f"around an area). Keep the child's original drawing fully intact underneath."
471 )
472
473
474
475 def build_combined_prompt(analysis: dict, width: int, height: int) -> str:
476     fh, theme, age, items, layout = _base_context(analysis)
477     adds = (fh.get("drawable_additions") or fh.get("suggested_additions", []))[:2]
478    imps = (fh.get("drawable_improvements") or fh.get("improvement_areas", []))[:2]
479     ap = _age_profile(age)
480     adds_text = "\n".join(f"    {s}" for s in adds if "[" not in s or " + Realistic age-appropriate addition"
481     imps_text = "\n".join(f"    {s}" for s in imps if "[" not in s or " Genuinely incomplete element for this ag
482     e"
483     return (
484         f"Drawing (age {age} – {ap['stage']}): {theme}\n"
485         f"Objects: {items}. Layout: {layout}.\n\n"
486         f"GREEN (#00CC44) – Good Cop: realistic additions for age {age}:\n{adds_text}\n\n"
487         f"RED (#FF3333) – Bad Cop: genuine incompleteness for age {age}:\n{imps_text}\n\n"
488         f"Age complexity: {ap['complexity']}. Keep original intact."
489     )
490
491
492 def _wild_brief(age: str) -> str:
493     """Age-tiered guidance on HOW sophisticated the wild idea should be."""
494     if age == "8-11":
495         return (
496             "LATE-CHILDHOOD wild ideas (8-11) must be CLEVER but CLEAR – ONE coherent idea,\n"
497             "NOT babyish and NOT a cluttered mess:\n"
498             "- ONE single transformation: reveal the MAIN object is secretly something else,\n"
499             "with a reason (\\"...which is why...\"). Smart CONCEPT, not lots of parts.\n"
500             "- It must read at a glance – a viewer should instantly 'get' the idea.\n"
501             "- Add only 1-2 small details that SUPPORT that one idea. Do NOT scatter gears,\n"
502             "panels, gauges, rivets or gadgets everywhere.\n"
503             "- Build the wildness ONTO the main object only; do NOT add marks to other objects.\n"
504             "- Stay grounded in THIS drawing."
505         )
506     if age == "5-7":
507         return ("Wild ideas for 5-7: playful, ONE imaginative transformation of a real object "
508             "(it flies, it grows wings, it turns into candy).")
509     if age == "2-4":
510         return ("Wild ideas for 2-4: very silly and simple, ONE tiny funny change to a real object "
511             "(it has a hat, it bounces, it giggles).")
512     return "One fun, surprising transformation of a real object already in the drawing."
513
514
515 def generate_wild_overlay(
516     client: genai.Client,
517     analysis: dict,
518     original: Image.Image,

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519 ) -> Image.Image | None:
520 """
521 Wild Cop – translates analysis wild_suggestions into explicit visual instructions,
522 then draws them faithfully. The analysis produces the ideas; this translates them
523 into "draw X on/near Y" language the image model actually follows.
524 """
525 import random as _r
526
527 age = analysis.get("inferred_age_group", "unknown")
528 theme = analysis.get("themes", {}).get("primary_theme", "a scene")
529 items_list = analysis.get("objects", {}).get("identified_objects", [])
530 items = ", ".join(items_list) or "figures"
531 mood = analysis.get("emotions", {}).get("overall_mood", "")
532 fh = analysis.get("feedback_hooks", {})
533 wilds = [w for w in fh.get("wild_suggestions", []) if w and "[object]" not in w]
534 ap = _age_profile(age)
535 w, h = original.size
536
537 if not wilds:
538     obj = items_list[0] if items_list else "the main figure"
539     obj2 = items_list[1] if len(items_list) > 1 else obj
540     if age == "8-11":
541         wilds = [
542             f"why isn't the {obj} secretly a robot in disguise, with the {obj2} as its remote control?",
543             f"why isn't the {obj} actually the periscope of a submarine hidden under the {obj2}?",
544         ]
545     else:
546         wilds = [
547             f"why isn't the {obj} wearing a tiny crown and singing to the moon?",
548             f"why isn't the {obj2} on a magic carpet flying through a rainbow?",
549         ]
550
551 idea1 = wilds[0]
552 idea2 = wilds[1] if len(wilds) > 1 else wilds[0]
553
554 def _mentions_object(text: str, objs: list) -> bool:
555     t = text.lower()
556     return any(o.lower() in t for o in objs if o)
557
558 def translate_to_visual(wild_idea: str, items_in_drawing: list) -> str:
559     """
560     Ask the analysis model to translate a 'why isn't X doing Y' idea into an
561     explicit visual instruction that is GROUNDED in this drawing – it must name
562     and act on a real object the child drew, never float unrelated in empty space.
563     """
564     objects_str = ", ".join(items_in_drawing) if items_in_drawing else "the main figure"
565     anchor = items_in_drawing[0] if items_in_drawing else "the main figure"
566     try:
567         resp = client.models.generate_content(
568             model=ANALYSIS_MODEL,
569             contents=[
570                 types.Part.from_bytes(data=to_bytes(original, "JPEG"), mime_type="image/jpeg"),
571                 types.Part.from_text(text=(
572                     f"You are looking at THIS child's drawing. It contains these exact "
573                     f"objects: {objects_str}.\n\n"
574                     f"Wild idea: \"{wild_idea}\".\n\n"
575                     f"Turn this into ONE concrete drawing instruction that is GROUNDED in "
576                     f"this specific drawing.\n"
577                     f"HARD RULES:\n"
578                     f"- The instruction MUST name and act on one of these exact objects: "
579                     f"{objects_str}.\n"
580                     f"- The new element must touch, sit on, grow from, or transform that "
581                     f"object – it may NOT float unrelated in empty space.\n"
582                     f"- Do NOT introduce a brand-new main subject that is not in the list "
583                     f"above (small accessories attached to a listed object are fine).\n"
584                     + (
585                         f"- AGE 8-11: make it CLEVER but CLEAR – reveal the {anchor} is secretly ONE\n"
586                         f"other thing, with a reason. Add only 1-2 small details that SUPPORT that\n"
587                         f"idea. Do NOT pile on gears/panels/gauges, and do NOT touch other objects.\n"
588                         f"if age == \"8-11\" else
589                         f"- Keep it to ONE BOLD, clear transformation suited to age {age} – "
590                         f"wild and surprising, but still a single readable idea.\n"
591                     )
592                     + f"Format: \"Draw [specific element(s)] on/from/around the [object from the list]\"\n"
593                     f"Examples (each names a real object and attaches to it):\n"
594                     + (
595                         f"- \"Reveal the {anchor} is secretly a hot-air balloon: draw a small basket\n"
596                         f"    hanging under it on two ropes – nothing else\"\n"
597                         f"- \"Turn the {anchor} into a wise old wizard: give it a tall pointed hat and a\n"
598                         f"    long curly beard, and keep it simple and clear\"\n"
599                         f"if age == \"8-11\" else
600                         f"- \"Draw a tiny golden crown on top of the {anchor}'s head\"\n"
601                         f"- \"Turn the {anchor} into a flying carpet with tassels lifting off the ground\"\n"
602                     )
603                     + f"Return ONLY the instruction sentence, nothing else."
604                 )),
605             ],
606         )

```

```

607         instruction = resp.text.strip().strip('""')
608         # Validation: if the model ignored the drawing's objects, force-anchor it.
609         if items_in_drawing and not _mentions_object(instruction, items_in_drawing):
610             instruction = f"{instruction.rstrip('.')}, attached directly to the {anchor}"
611             print(f"        (re-anchored to '{anchor}')"
612             print(f"        Translated: {instruction[:80]}")
613         return instruction
614     except Exception as e:
615         print(f"        Translation failed: {e}")
616         # The raw wild idea already names a real object from the drawing – keep it
617         # (just drop the "why isn't ...?" framing) rather than collapsing to a generic
618         # transform of the first object. Preserves context when the API is down.
619         cleaned = wild_idea.strip().rstrip("?").strip()
620         for pre in ("why isn't ", "why isn't ", "why is ", "why aren't ", "why aren't "):
621             if cleaned.lower().startswith(pre):
622                 cleaned = cleaned[len(pre):]
623                 break
624         return cleaned or f"Transform the {anchor} in a surprising, magical way"
625
626     print(f"        Wild idea 1: {idea1[:70]}")
627     print(f"        Wild idea 2: {idea2[:70]}")
628     print(f"        Translating to visual instructions...")
629
630     visual1 = translate_to_visual(idea1, items_list)
631     visual2 = translate_to_visual(idea2, items_list)
632
633     print(f"        Visual 1: {visual1[:70]}")
634     print(f"        Visual 2: {visual2[:70]}")
635
636     # Gender balance
637     emotional_theme = analysis.get("themes", {}).get("emotional_theme", "").lower()
638     if any(x in emotional_theme for x in ["princess", "fairy", "flower", "love", "heart"]):
639         tone = "gentle, magical, sparkly"
640     elif any(x in emotional_theme for x in ["robot", "action", "fight", "car", "space"]):
641         tone = "bold, action-packed, energetic"
642     else:
643         tone = "balanced – one gentle, one adventurous"
644
645     brief = _wild_brief(age)
646
647     prompt = (
648         f"You are WILD COP drawing on a child's drawing (age {age}).\n"
649         f"Drawing shows: {theme}. It contains these exact objects: {items}. Mood: {mood}.\n\n"
650         f"AGE BRIEF:\n{brief}\n\n"
651         f"Draw EXACTLY these 2 wild additions on the drawing:\n\n"
652         f"ADDITION 1: {visual1}\n"
653         f"Label it with a short fun ALL-CAPS text: pick 1-2 words from the idea.\n\n"
654         f"ADDITION 2: {visual2}\n"
655         f"Label it with a short fun ALL-CAPS text: pick 1-2 words from the idea.\n\n"
656         f"Tone: {tone} | Age style: {ap['wild_style']}\n\n"
657         f"CONTEXT RULE (most important):\n"
658         f"- Both additions MUST visibly connect to objects the child already drew "
659         f"f"({items}).\n"
660         f"- Each new mark should touch, sit on, grow from, or transform one of those "
661         f"objects – NO floating, unrelated elements in empty space.\n"
662         f"- Do NOT invent a new main subject; build the wildness ONTO what is there.\n\n"
663         f"KEEP IT COHERENT (just as important):\n"
664         f"- Each addition is ONE clear idea that reads at a glance – NOT a busy pile of\n"
665         f"  gears, panels, gauges, wires or scattered gadgets.\n"
666         f"- Build onto the MAIN object. Do NOT add thought-bubbles, gadgets or extra marks\n"
667         f"  onto small or secondary objects in the drawing.\n"
668         f"- If someone glanced at it, they should INSTANTLY understand the wild idea.\n\n"
669         f"DRAWING RULES:\n"
670         f"- Draw the ACTUAL SHAPE of each wild addition as an outline the child can\n"
671         f"  trace over – NEVER a rectangle, box, or frame around an empty area\n"
672         f"- DRAW IT WITH CLEAR, RECOGNISABLE DETAIL so the child can sketch it: show the\n"
673         f"  parts that make the wild idea READ (dragon = scales + wings + horns + a fiery\n"
674         f"  mouth; rocket = nose cone + fins + flames; crown = points + jewels). Each part\n"
675         f"  clearly separated, not a vague blob.\n"
676         f"- Draw in the SAME crayon style as the original\n"
677         f"- Clean, confident dashed lines – clearly visible to trace, but not so heavy they\n"
678         f"  hide the child's original drawing\n"
679         f"- Purple (#CC00FF) ONLY for all new marks and labels\n"
680         f"- ONE label + ONE arrow per addition, keep labels short\n"
681         f"- Keep original drawing 100% visible underneath\n"
682         f"- EXACTLY 2 additions – no more, no backgrounds, no extra elements"
683     )
684
685     img_bytes = to_bytes(original, "JPEG")
686
687     for attempt in range(1, MAX_RETRIES + 1):
688         try:
689             if attempt > 1:
690                 time.sleep(12 * (attempt - 1))
691                 print(f"        Retry {attempt}...")
692             resp = client.models.generate_content(
693                 model=IMAGE_MODEL,
694                 contents=[

```

```

695         types.Part.from_bytes(data=img_bytes, mime_type="image/jpeg"),
696         types.Part.from_text(text=prompt),
697     ],
698     config=types.GenerateContentConfig(response_modalities=["IMAGE", "TEXT"]),
699 )
700 for part in resp.candidates[0].content.parts:
701     if hasattr(part, "text") and part.text:
702         print(f"    Model: {part.text[:80]}")
703     if part.inline_data and part.inline_data.mime_type.startswith("image/"):
704         img = Image.open(BytesIO(part.inline_data.data)).convert("RGB")
705         if img.size != (w, h):
706             img = img.resize((w, h), Image.LANCZOS)
707         print(f"    Wild Cop generated {img.size}")
708         return img
709     print(f"    No image returned (attempt {attempt})")
710 except ServerError as e:
711     print(f"    Server error: {e}")
712 except Exception as e:
713     import traceback
714     print(f"    Error: {e}")
715     traceback.print_exc()
716
717 print("    All attempts failed – using PIL fallback")
718 return _wild_cop_pil_fallback(analysis, w, h)
719
720
721 # — PIL fallback for Wild Cop —————
722
723 def _wild_cop_pil_fallback(analysis: dict, w: int, h: int) -> Image.Image:
724     """Bold PIL fallback when AI generation fails. Draws 4 wild elements."""
725     import math as _m
726     P = (140, 0, 220) # neon purple
727     O = (255, 100, 0) # orange
728     img = Image.new("RGB", (w, h), (255, 255, 255))
729     draw = ImageDraw.Draw(img)
730
731     def dl(x0,y0,x1,y1,c=P,wd=2,d=7,g=4):
732         dx,dy=x1-x0,y1-y0; ln=_m.hypot(dx,dy)
733         if ln==0: return
734         ux,uy=dx/ln,dy/ln; pos,on=0,True
735         while pos<ln:
736             seg=d if on else g; ep=min(pos+seg,ln)
737             if on: draw.line([(x0+ux*pos,y0+uy*pos),(x0+ux*ep,y0+uy*ep)],fill=c,width=wd)
738             pos+=seg; on=not on
739
740     def dc(cx,cy,r,c=P,wd=2,s=32):
741         pts=[(cx+r*_m.cos(2*_m.pi*i/s),cy+r*_m.sin(2*_m.pi*i/s)) for i in range(s+1)]
742         for i in range(0,s,2): draw.line([pts[i],pts[i+1]],fill=c,width=wd)
743
744     def lbl(x,y,t,c=P,sz=16):
745         try:
746             from PIL import ImageFont; font=ImageFont.truetype("arial.ttf",sz)
747         except Exception: font=None
748         draw.text((int(x),int(y)),t,fill=c,font=font)
749
750     r = min(w,h)//9
751     # Rocket top-left
752     cx,cy=w//5,h//4
753     dl(cx,cy-r,cx-r//3,cy+r//2); dl(cx,cy-r,cx+r//3,cy+r//2)
754     dl(cx-r//3,cy+r//2,cx+r//3,cy+r//2); dc(cx,cy-r//4,r//5)
755     lbl(cx+r+5,cy-r//2," ROCKET!")
756     # Unicorn top-right
757     cx,cy=w*4//5,h//4
758     dc(cx,cy,r//2); dl(cx,cy-r//2,cx+r//4,cy-r,0,2)
759     dl(cx-r//2,cy,cx-r*3//2,cy+r//4); dl(cx+r//2,cy,cx+r*3//2,cy+r//4)
760     lbl(cx+r+5,cy-r//2," UNICORN!",0)
761     # Dragon bottom-left
762     cx,cy=w//5,h*3//4
763     dc(cx,cy,r//2); dc(cx+r//2,cy-r//3,r//4)
764     dl(cx-r//2,cy+r//3,cx-r,cy+r//2)
765     for i in range(3):
766         a=_m.radians(-30+i*30)
767         dl(cx-r*2//3,cy-r//5,int(cx-r*2//3-r//2*_m.cos(a)),int(cy-r//5-r//2*abs(_m.sin(a))))
768     lbl(cx+r+5,cy-r//2," DRAGON!")
769     # Castle bottom-right
770     cx,cy=w*4//5,h*3//4
771     dl(cx-r,cy-r//2,cx+r,cy-r//2,0); dl(cx-r,cy-r//2,cx-r,cy+r//2,0)
772     dl(cx+r,cy-r//2,cx+r,cy+r//2,0); dl(cx-r,cy+r//2,cx+r,cy+r//2,0)
773     for bx in [cx-r,cx-r//3,cx+r//3,cx+r-8]: dl(bx,cy-r,bx+8,cy-r//2,0)
774     lbl(cx+r+5,cy-r//2," CASTLE!",0)
775     return img
776
777
778
779 # — Extraction —————
780
781 def mask_original_from_annotated(
782     original: Image.Image,

```



```

783     annotated: Image.Image,
784     diff_threshold: int = 30,
785 ) -> Image.Image:
786     orig = np.array(original.convert("RGB")).astype(np.float32)
787     ann = np.array(annotated.convert("RGB")).astype(np.float32)
788     diff = np.abs(ann - orig).max(axis=2)
789     is_new = diff > diff_threshold
790     is_new_on_white = (orig.min(axis=2) > 220) & (ann.min(axis=2) < 200)
791     is_mark = is_new | is_new_on_white
792     try:
793         from scipy.ndimage import binary_dilation, label as ndlabel
794         labeled, n = ndlabel(is_mark)
795         clean = np.zeros_like(is_mark)
796         for i in range(1, n + 1):
797             if (labeled == i).sum() >= 8:
798                 clean |= (labeled == i)
799         is_mark = clean
800     except ImportError:
801         pass
802     result = np.ones_like(ann) * 255
803     result[is_mark] = ann[is_mark]
804     print(f"    Extracted {is_mark.sum()} mark pixels ({int(is_mark.mean()*100)}% canvas)")
805     return Image.fromarray(result.astype(np.uint8))
806
807
808 def _color_mask(arr: np.ndarray, color: str) -> np.ndarray:
809     """Boolean mask of pixels that are the AI's bright mark colour
810     (green #00CC44, red #FF3333, purple #CC00FF) – not generic drawing colours."""
811     r = arr[..., 0].astype(np.int16)
812     g = arr[..., 1].astype(np.int16)
813     b = arr[..., 2].astype(np.int16)
814     if color == "green":
815         return (g > 100) & (g - r > 40) & (g - b > 25)
816     if color == "red":
817         return (r > 110) & (r - g > 55) & (r - b > 55)
818     if color == "purple":
819         return (r > 80) & (b > 80) & (r - g > 45) & (b - g > 45)
820     return np.zeros(arr.shape[:2], dtype=bool)
821
822
823 def register_annotated(original: Image.Image, annotated: Image.Image) -> Image.Image:
824     """Warp the AI's (re)generated image back onto the ORIGINAL's frame using ORB
825     feature matching, so the marks land where they belong. The image model tends to
826     redraw the whole picture slightly shifted; this re-registers it. Falls back to
827     the unchanged annotated image whenever matching looks unreliable (e.g. very
828     abstract drawings with few features) so it can never make alignment worse."""
829     try:
830         import cv2
831         o_rgb = np.array(original.convert("RGB"))
832         a_rgb = np.array(annotated.convert("RGB"))
833         if a_rgb.shape != o_rgb.shape:
834             annotated = annotated.resize(original.size, Image.LANCZOS)
835             a_rgb = np.array(annotated.convert("RGB"))
836         og = cv2.cvtColor(o_rgb, cv2.COLOR_RGB2GRAY)
837         ag = cv2.cvtColor(a_rgb, cv2.COLOR_RGB2GRAY)
838         orb = cv2.ORB_create(2000)
839         k1, d1 = orb.detectAndCompute(ag, None) # source: annotated
840         k2, d2 = orb.detectAndCompute(og, None) # target: original
841         if d1 is None or d2 is None or len(k1) < 25 or len(k2) < 25:
842             return annotated
843         bf = cv2.BFMatcher(cv2.NORM_HAMMING, crossCheck=True)
844         matches = sorted(bf.match(d1, d2), key=lambda m: m.distance)[:150]
845         if len(matches) < 20:
846             return annotated
847         src = np.float32([k1[m.queryIdx].pt for m in matches]).reshape(-1, 1, 2)
848         dst = np.float32([k2[m.trainIdx].pt for m in matches]).reshape(-1, 1, 2)
849         H, _ = cv2.findHomography(src, dst, cv2.RANSAC, 5.0)
850         if H is None:
851             return annotated
852         # Sanity: only a gentle correction is plausible – reject wild warps.
853         if (abs(H[0, 0] - 1) > 0.45 or abs(H[1, 1] - 1) > 0.45 or
854             abs(H[2, 0]) > 0.0025 or abs(H[2, 1]) > 0.0025):
855             return annotated
856         h, w = og.shape
857         warped = cv2.warpPerspective(a_rgb, H, (w, h), borderValue=(255, 255, 255))
858         print(f"    [register] aligned generated image to original")
859         return Image.fromarray(warped)
860     except Exception as e:
861         print(f"    [register] skipped: {e}")
862     return annotated
863
864
865 def extract_color_marks(
866     original: Image.Image,
867     annotated: Image.Image,
868     color: str, # "green" | "red" | "purple"
869     diff_threshold: int = 40,
870 ) -> Image.Image | None:

```

```

871 """Isolate ONLY the AI's coloured marks (after re-registering the image to the
872 original frame), so the projected overlay lines up and is free of redraw noise."""
873 if annotated is None:
874     return None
875 # NOTE: no geometric re-registration – we keep the AI's marks exactly where it
876 # drew them (pure AI output). We only colour-isolate to drop redraw noise.
877 orig = np.array(original.convert("RGB")).astype(np.int16)
878 ann = np.array(annotated.convert("RGB")).astype(np.int16)
879 if ann.shape != orig.shape:
880     annotated = annotated.resize(original.size, Image.LANCZOS)
881     ann = np.array(annotated.convert("RGB")).astype(np.int16)
882 cmask = _color_mask(ann, color)
883 diff = np.abs(ann - orig).max(axis=2) # the mark must be NEW vs original
884 is_mark = cmask & (diff > diff_threshold)
885 try:
886     from scipy.ndimage import label as ndlabel
887     labeled, n = ndlabel(is_mark)
888     clean = np.zeros_like(is_mark)
889     for i in range(1, n + 1):
890         if (labeled == i).sum() >= 12: # drop tiny specks
891             clean |= (labeled == i)
892     is_mark = clean
893 except ImportError:
894     pass
895 result = np.ones_like(ann) * 255
896 result[is_mark] = ann[is_mark]
897 print(f"    Extracted {int(is_mark.sum())} {color} mark px ({is_mark.mean()*100:.1f}% canvas)")
898 return Image.fromarray(result.astype(np.uint8))
899
900
901 def extract_overlay_marks(original: Image.Image, annotated: Image.Image) -> Image.Image:
902     return mask_original_from_annotated(original, annotated, diff_threshold=30)
903
904
905 def extract_wild_marks(original: Image.Image, wild: Image.Image) -> Image.Image:
906     return mask_original_from_annotated(original, wild, diff_threshold=25)
907
908
909 # — Analysis —————
910
911 def run_analysis(
912     client: genai.Client,
913     image: Image.Image,
914     age_group: str = "unknown",
915     master_context: str = "",
916 ) -> dict | None:
917     sys_p = (master_context + "\n\n" + BASE_SYS).strip() if master_context else BASE_SYS
918     age_ln = f"Age group: {age_group}. " if age_group != "unknown" else ""
919     prompt = age_ln + ANALYSIS_PROMPT
920     for attempt in range(1, MAX_RETRIES + 1):
921         try:
922             if attempt > 1: time.sleep(8 * attempt)
923             resp = client.models.generate_content(
924                 model=ANALYSIS_MODEL,
925                 contents=[
926                     types.Part.from_text(text=sys_p + "\n\n" + prompt),
927                     types.Part.from_bytes(data=to_bytes(image), mime_type="image/jpeg"),
928                 ],
929                 config=types.GenerateContentConfig(response_mime_type="application/json"),
930             )
931             raw = resp.text.strip()
932             # Debug: show first 300 chars of raw response
933             print(f"    [Analysis raw] {raw[:300]}")
934             a = json.loads(raw)
935             tct = a.get("tct_dp_score", {})
936             tct["tct_dp_total"] = sum(1 for k in TCT_KEYS if tct.get(k))
937             # Debug: check key fields
938             fh = a.get("feedback_hooks", {})
939             print(f"    [Analysis keys] themes:{bool(a.get('themes'))} "
940                   f"fh_keys:{list(fh.keys())[:5]} "
941                   f"adds:{len(fh.get('drawable_additions', []))} "
942                   f"wilds:{len(fh.get('wild_suggestions', []))}")
943             return a
944         except Exception as e:
945             print(f"    [Analysis] attempt {attempt} error: {e}")
946             if attempt == MAX_RETRIES:
947                 return None
948
949
950 def print_summary(analysis: dict) -> None:
951     fh = analysis.get("feedback_hooks", {})
952     tct = analysis.get("tct_dp_score", {})
953     adds = fh.get("drawable_additions") or fh.get("suggested_additions", [])
954    imps = fh.get("drawable_improvements") or fh.get("improvement_areas", [])
955     wilds = fh.get("wild_suggestions", [])
956     print(f"    Theme: {analysis.get('themes', {}).get('primary_theme', '?')} | "
957           f"Age: {analysis.get('inferred_age_group', '?')} | "
958           f"TCT-DP: {tct.get('tct_dp_total', 0)}/14")

```

```

959     print(f" Mood: {analysis.get('emotions', {}).get('overall_mood', '?')}")
960     for s in adds: print(f" + {s}")
961     for s in imps: print(f" {s}")
962     for s in wilds: print(f" ? {s}")
963     if not wilds: print(" ? (no wild suggestions)")
964
965
966 # — Overlay helpers —————
967
968 def build_full_overlay(original: Image.Image, marks: Image.Image) -> Image.Image:
969     orig_arr = np.array(original.convert("RGBA"))
970     marks_arr = np.array(marks.convert("RGBA"))
971     white = (marks_arr[:,0]>240) & (marks_arr[:,1]>240) & (marks_arr[:,2]>240)
972     result = orig_arr.copy()
973     result[~white] = marks_arr[~white]
974     return Image.fromarray(result, "RGBA").convert("RGB")
975
976
977 def build_projector_output(marks: Image.Image) -> Image.Image:
978     return marks
979
980
981 # — Run pipeline —————
982
983 def describe_overlay(
984     client: genai.Client,
985     original: Image.Image,
986     overlay: Image.Image,
987     cop_type: str, # "good", "bad", or "wild"
988 ) -> list[str]:
989     """
990     After generating an overlay, ask the model to describe what was actually added.
991     Returns 1-2 short strings matching what was drawn – used as the displayed suggestions.
992     """
993     if overlay is None:
994         return []
995
996     role = {
997         "good": "green dashed outlines showing new elements the child could add",
998         "bad": "red dashed marks showing small realistic improvements drawn ON the existing objects (e.g. a door on
999             the house, a trunk under the tree, water around the fish)",
1000         "wild": "purple wild/surreal additions to the drawing",
1001     }.get(cop_type, "overlay marks")
1002
1003     prompt = (
1004         f"I am showing you two images: the original child's drawing and an annotated version "
1005         f"with {role} added on top.\n\n"
1006         f"Look at what was actually drawn/added in the annotated version.\n"
1007         f"List EXACTLY what new marks or elements appear – be specific and brief.\n"
1008         f"Use SIMPLE, CONCRETE words a young child would understand. Name a real thing\n"
1009         f"and where it is. NEVER use art jargon (horizon, composition, perspective,\n"
1010         f"depth, ground line) – say 'a line where the grass meets the sky', 'the ground\n"
1011         f"under their feet', 'water around the fish' instead.\n"
1012         f"Return ONLY a JSON array of 1-3 short strings describing each addition.\n"
1013         f"Example: [\"a butterfly in the top right\", \"a cloud in the sky\"]\n"
1014         f"Example: [\"green grass under the house\", \"a road under the car\"]\n"
1015         f"Example: [\"a unicorn flying across the sky\", \"a rocket behind the house\"]\n"
1016         f"Return ONLY the JSON array, no other text."
1017     )
1018
1019     orig_bytes = to_bytes(original, "JPEG")
1020     overlay_bytes = to_bytes(overlay, "JPEG")
1021
1022     try:
1023         resp = client.models.generate_content(
1024             model=ANALYSIS_MODEL,
1025             contents=[
1026                 types.Part.from_bytes(data=orig_bytes, mime_type="image/jpeg"),
1027                 types.Part.from_bytes(data=overlay_bytes, mime_type="image/jpeg"),
1028                 types.Part.from_text(text=prompt),
1029             ],
1030             config=types.GenerateContentConfig(response_mime_type="application/json"),
1031         )
1032         result = json.loads(resp.text.strip())
1033         if isinstance(result, list):
1034             return [str(s) for s in result[:3]]
1035     except Exception as e:
1036         print(f" [describe_overlay] {e}")
1037     return []
1038
1039
1040 def run_pipeline(
1041     image_path: str,
1042     age_group: str = "unknown",
1043     out_dir: str | None = None,
1044     master_context: str | None = None,
1045     analysis_only: bool = False,

```

```

1046 ) -> dict:
1047     client = genai.Client(api_key=load_api_key())
1048     original = load_image(image_path)
1049     w, h = original.size
1050     stem = Path(image_path).stem
1051     out = Path(out_dir) if out_dir else Path(image_path).parent
1052     out.mkdir(parents=True, exist_ok=True)
1053     mc = load_master_context(master_context)
1054
1055     print(f"\nLe Magique | {Path(image_path).name} ({w}x{h}) | age: {age_group}")
1056
1057     analysis = run_analysis(client, original, age_group, mc)
1058     if not analysis:
1059         print("[!] Analysis failed.")
1060         return {}
1061
1062     print_summary(analysis)
1063     json_path = out / f"{stem}_analysis.json"
1064     json_path.write_text(json.dumps(analysis, indent=2, ensure_ascii=False), encoding="utf-8")
1065
1066     if analysis_only:
1067         return {"analysis": analysis, "analysis_path": str(json_path)}
1068
1069     import time as _t
1070     from concurrent.futures import ThreadPoolExecutor
1071
1072     print("\n[2/4] Generating overlays...")
1073     t0 = _t.time()
1074     img_bytes = to_bytes(original, "JPEG")
1075
1076     def _gen(prompt: str, label: str) -> Image.Image | None:
1077         for attempt in range(1, MAX_RETRIES + 1):
1078             try:
1079                 if attempt > 1: _t.sleep(10*(attempt-1))
1080                 resp = client.models.generate_content(
1081                     model=IMAGE_MODEL,
1082                     contents=[
1083                         types.Part.from_bytes(data=img_bytes, mime_type="image/jpeg"),
1084                         types.Part.from_text(text=prompt),
1085                     ],
1086                     config=types.GenerateContentConfig(response_modalities=["IMAGE", "TEXT"]),
1087                 )
1088                 for part in resp.candidates[0].content.parts:
1089                     if part.inline_data and part.inline_data.mime_type.startswith("image/"):
1090                         img = Image.open(BytesIO(part.inline_data.data)).convert("RGB")
1091                         if img.size != (w, h): img = img.resize((w, h), Image.LANCZOS)
1092                         print(f"    {label}")
1093                         return img
1094             except ServerError as e:
1095                 print(f"    Server error ({label}): {e}")
1096             except Exception as e:
1097                 print(f"    Error ({label}): {e}")
1098         return None
1099
1100     # All three overlays generate concurrently – the slowest single call sets the
1101     # pace instead of two sequential rounds (~40% faster than Good+Bad then Wild).
1102     with ThreadPoolExecutor(max_workers=3) as ex:
1103         fg = ex.submit(_gen, build_good_cop_prompt(analysis, w, h), "Good Cop")
1104         fb = ex.submit(_gen, build_bad_cop_prompt(analysis, w, h), "Bad Cop")
1105         fw = ex.submit(generate_wild_overlay, client, analysis, original)
1106         good_ann, bad_ann, wild_ann = fg.result(), fb.result(), fw.result()
1107
1108     print(f"    Good+Bad+Wild done in {_t.time()-t0:.1f}s")
1109
1110     # All three = sparse coloured marks, colour-isolated (no re-registration, so the
1111     # AI's own placement is kept). Good=green additions, Bad=red improvements, Wild=purple.
1112     good_marks = extract_color_marks(original, good_ann, "green") if good_ann else None
1113     bad_marks = extract_color_marks(original, bad_ann, "red") if bad_ann else None
1114     wild_marks = extract_color_marks(original, wild_ann, "purple") if wild_ann else None
1115
1116     # — Describe what was actually generated (for consistent text/visual output)
1117     # Pass the ANNOTATED image (marks over the drawing, with labels) – not the
1118     # marks-on-white – so the model reads the suggestion in context instead of
1119     # just seeing "red dashed lines". All three descriptions run concurrently too.
1120     print("\n[3/4] Describing generated overlays...")
1121     t1 = _t.time()
1122     with ThreadPoolExecutor(max_workers=3) as ex:
1123         fgd = ex.submit(describe_overlay, client, original, good_ann, "good") if good_marks else None
1124         fbd = ex.submit(describe_overlay, client, original, bad_ann, "bad") if bad_marks else None
1125         fwd = ex.submit(describe_overlay, client, original, wild_ann, "wild") if wild_marks else None
1126         good_desc = fgd.result() if fgd else []
1127         bad_desc = fbd.result() if fbd else []
1128         wild_desc = fwd.result() if fwd else []
1129     print(f"    Descriptions done in {_t.time()-t1:.1f}s")
1130
1131     # — Guarantee suggestions are NEVER blank
1132     # If the describe step came back empty (sparse marks, transient API error),
1133     # fall back to the analysis's own suggestions, then to an object-derived line.

```

```

1134 fh0 = analysis.get("feedback_hooks", {})
1135 objs = analysis.get("objects", {}).get("identified_objects") or []
1136 obj0 = objs[0] if objs else "drawing"
1137
1138 def _nz(lst):
1139     # non-empty, stripped strings only
1140     return [s.strip() for s in (lst or []) if s and str(s).strip()]
1141
1142 def _clean_wild(items):
1143     # drop "why isn't ...?" framing for display
1144     out = []
1145     for s in _nz(items):
1146         for pre in ("why isn't ", "why isnt ", "why is ", "why aren't ",
1147                    "why arent ", "what if "):
1148             if s.lower().startswith(pre):
1149                 s = s[len(pre):]; break
1150             s = s.rstrip("?.").strip()
1151             if s: out.append(s[0].upper() + s[1:])
1152     return out
1153
1154 if not _nz(good_desc):
1155     good_desc = _nz(fh0.get("drawable_additions")) or [f"Add something new beside the {obj0}"]
1156 if not _nz(bad_desc):
1157     bad_desc = _nz(fh0.get("drawable_improvements")) or [f"Add a missing detail to the {obj0}"]
1158 if not _nz(wild_desc):
1159     wild_desc = _clean_wild(fh0.get("wild_suggestions")) or \
1160         [f"The {obj0} secretly turns into something magical and zooms off on an adventure"]
1161
1162 print("\n    What was actually generated:")
1163 print(f"    Good Cop: {good_desc}")
1164 print(f"    Bad Cop: {bad_desc}")
1165 print(f"    Wild Cop: {wild_desc}")
1166
1167 # Update analysis feedback_hooks with actual generated content
1168 fh = analysis.setdefault("feedback_hooks", {})
1169 if good_desc: fh["drawable_additions"] = good_desc
1170 if bad_desc: fh["drawable_improvements"] = bad_desc
1171 if wild_desc: fh["wild_suggestions"] = wild_desc
1172
1173 print("\n[4/4] Saving...")
1174 def sv(img, name):
1175     if img:
1176         p = out / f"{stem}_{name}"
1177         img.save(str(p))
1178         print(f"    {p.name}")
1179         return str(p)
1180
1181 sv(good_marks, "1_good_cop.png")
1182 sv(good_ann, "1a_good_cop_full.png")
1183 sv(bad_marks, "2_bad_cop.png")
1184 sv(bad_ann, "2a_bad_cop_full.png")
1185 sv(wild_marks, "3_wild_cop.png")
1186 sv(wild_ann, "3a_wild_cop_full.png")
1187
1188 # Save updated analysis with actual descriptions
1189 json_path.write_text(json.dumps(analysis, indent=2, ensure_ascii=False), encoding="utf-8")
1190
1191 return {
1192     "analysis": analysis,
1193     "good_cop_path": str(out/f"{stem}_1_good_cop.png") if good_marks else None,
1194     "bad_cop_path": str(out/f"{stem}_2_bad_cop.png") if bad_marks else None,
1195     "wild_cop_path": str(out/f"{stem}_3_wild_cop.png") if wild_marks else None,
1196     "good_cop_desc": good_desc,
1197     "bad_cop_desc": bad_desc,
1198     "wild_cop_desc": wild_desc,
1199 }
1200
1201 # — CLI —
1202
1203 if __name__ == "__main__":
1204     import argparse
1205     parser = argparse.ArgumentParser(description="Le Magique Drawing Pipeline")
1206     parser.add_argument("--image", required=True)
1207     parser.add_argument("--age-group", default="unknown",
1208                         choices=["unknown", "2-4", "5-7", "8-11"])
1209     parser.add_argument("--out-dir", default=None)
1210     parser.add_argument("--master-context", default=None)
1211     parser.add_argument("--analysis-only", action="store_true")
1212     args = parser.parse_args()
1213     run_pipeline(
1214         image_path=args.image, age_group=args.age_group,
1215         out_dir=args.out_dir, master_context=args.master_context,
1216         analysis_only=args.analysis_only,
1217     )

```


Appendix E.2 - le_magique_controller.py

Flask Controller – Camera, Projector, Recording, Auto-Analysis Loop

```
1  #!/usr/bin/env python3
2  """
3  Le Magique Laptop Controller – Camera + Projector
4  -----
5  Connects the Logitech C270 webcam and Cahaya projector to your laptop.
6
7  Flow:
8  1. Click "Capture" → C270 takes a photo of the drawing
9     (or upload an image manually)
10 2. Click "Analyse + Generate" → pipeline runs
11 3. Click "Good Cop" or "Bad Cop" button
12 4. Overlay appears in browser AND is sent fullscreen to the projector
13
14 Requirements:
15     pip install flask google-genai pillow numpy opencv-python
16
17 Usage:
18     export GEMINI_API_KEY=your_key    (Windows: $env:GEMINI_API_KEY="...")
19     python le_magique_controller.py
20
21     # If C270 is on a different USB index:
22     python le_magique_controller.py --camera 1
23 """
24
25 import os, json, time, threading, sys, argparse
26 from pathlib import Path
27 from datetime import datetime
28
29 import numpy as np
30 from PIL import Image, ImageDraw
31 from flask import Flask, request, jsonify, send_file, Response
32
33 try:
34     import cv2
35     CV2_AVAILABLE = True
36 except ImportError:
37     CV2_AVAILABLE = False
38
39 try:
40     import tkinter as tk
41     from PIL import ImageTk
42     TK_AVAILABLE = True
43 except ImportError:
44     TK_AVAILABLE = False
45
46 # Le Magique generation pipeline (shared, refined Good / Bad / Wild Cop logic)
47 sys.path.insert(0, str(Path(__file__).parent))
48 try:
49     # Single source of truth – the controller delegates the whole analyse →
50     # generate → describe flow to run_pipeline (identical to the dashboard).
51     from drawing_edit_pipeline import run_pipeline as dep_run_pipeline
52     PIPELINE_OK = True
53 except Exception as _e:
54     PIPELINE_OK = False
55     print(f"!! drawing_edit_pipeline import failed: {_e}")
56
57 # — Config —————
58
59 WORK_DIR = Path.home() / "Desktop" / "le_magique_outputs"
60 MASTER_CONTEXT_PATHS = [
61     Path("MASTER_CONTEXT.json"),
62     Path.home() / "Desktop" / "MASTER_CONTEXT.json",
63     Path.home() / "Downloads" / "MASTER_CONTEXT.json",
64 ]
65 CAMERA_INDEX = 0 # overridden by --camera arg
66
67 # The camera + projector are mounted overhead and upside down (180°).
68 # • CAM_ROTATE_180 – flip every captured frame upright before analysis/recording.
69 # • PROJ_ROTATE_180 – flip the overlay 180° before projecting so the marks land
70 #                     the right way up on the paper through the upside-down projector.
71 # Toggle these with --no-cam-flip / --no-proj-flip if your rig is mounted upright.
72 CAM_ROTATE_180 = True
73 PROJ_ROTATE_180 = True
74
75 WORK_DIR.mkdir(parents=True, exist_ok=True)
76 REC_DIR = Path.home() / "Desktop" / "le_magique_recordings"
77 paths = {
78     "upload": WORK_DIR / "current_drawing.jpg",
79     "full": WORK_DIR / "overlay_full.png",
80     "good_cop": WORK_DIR / "overlay_good_cop.png",
81     "bad_cop": WORK_DIR / "overlay_bad_cop.png",
82     "wild_cop": WORK_DIR / "overlay_wild_cop.png",
83 }
```

```

84     # Laptop-view composites: the child's drawing WITH the overlay marks on top
85     "comp_good_cop": WORK_DIR / "composite_good_cop.png",
86     "comp_bad_cop": WORK_DIR / "composite_bad_cop.png",
87     "comp_wild_cop": WORK_DIR / "composite_wild_cop.png",
88     "analysis": WORK_DIR / "analysis.json",
89     "blank": WORK_DIR / "blank.png",
90 }
91 # "Active" buffer = the overlay set currently available to project. The pipeline
92 # always writes the LATEST set to the keys above; Refresh promotes latest -> active
93 # so the live projection only changes when the user asks.
94 ACTIVE_KEYS = ["good_cop", "bad_cop", "wild_cop", "full",
95               "comp_good_cop", "comp_bad_cop", "comp_wild_cop"]
96 for _k in ACTIVE_KEYS:
97     paths["active_" + _k] = WORK_DIR / ("active_" + paths[_k].name)
98 CALIB_FILE = Path(__file__).parent / "projector_calibration.json"
99
100 # Black image (projector shows nothing until an overlay is sent)
101 Image.new("RGB", (1280, 720), (0, 0, 0)).save(str(paths["blank"]))
102
103 # — Pipeline state —————
104
105 pipeline_state = {
106     "status": "idle", "step": "", "progress": 0,
107     "age_group": None, "theme": None, "mood": None, "tct": None,
108     "good_cop_suggestions": [], "bad_cop_suggestions": [], "wild_cop_suggestions": [],
109     "engagement_trigger": "", "error": "",
110     "overlays_ready": {"full": False, "good_cop": False, "bad_cop": False, "wild_cop": False},
111     "projecting": None,
112     "camera_available": CV2_AVAILABLE,
113     "recording": False, # video recording active
114     "auto": False, # auto-analysis loop active (runs while recording)
115     "auto_state": "idle", # idle | analysing | ready
116     "gen_id": 0, # increments each time a new (latest) overlay set is ready
117     "pending_refresh": False, # a newer set is staged, waiting for Refresh
118     "active_ready": {"full": False, "good_cop": False, "bad_cop": False, "wild_cop": False},
119     "current_projection": None, # which personality is on the projector (good_cop/...)
120 }
121
122
123 def commit_active() -> None:
124     """Promote the latest generated overlays to the ACTIVE buffer (what gets
125     projected). Called for the first set automatically and on every Refresh."""
126     import shutil
127     for k in ACTIVE_KEYS:
128         src, dst = paths[k], paths["active_" + k]
129         if Path(src).exists():
130             try:
131                 shutil.copyfile(str(src), str(dst))
132             except Exception as e:
133                 print(f"[Active] copy {k} failed: {e}")
134     for p in ("good_cop", "bad_cop", "wild_cop", "full"):
135         pipeline_state["active_ready"][p] = Path(paths["active_" + p]).exists()
136     print("[Active] overlay set committed (now projectable)")
137
138
139 # — Camera (continuous stream – keeps the latest frame) —————
140
141 _cam = {"cap": None, "frame": None, "lock": threading.Lock(),
142        "run": False, "index": CAMERA_INDEX}
143
144 # Continuous video recording (for building a time-lapse later)
145 _rec = {"writer": None, "on": False, "path": None,
146        "frames": 0, "lock": threading.Lock(), "started": None}
147
148 # Auto-analysis loop: while recording, grab a frame every N seconds and pre-generate
149 # overlays – but PAUSE while an overlay is being projected (resume on Blank screen).
150 _auto = {"on": False, "thread": None, "interval": 30}
151
152
153 def start_recording() -> dict:
154     """Begin writing every streamed frame to a timestamped video file."""
155     if not CV2_AVAILABLE:
156         return {"error": "OpenCV not installed."}
157     if not _cam["run"]:
158         return {"error": "Camera stream not running."}
159     with _rec["lock"]:
160         if _rec["on"]:
161             return {"ok": True, "path": str(_rec["path"]), "already": True}
162         frame = grab_latest_frame()
163         if frame is None:
164             return {"error": "No camera frame yet – try again in a second."}
165         h, w = frame.shape[:2]
166         REC_DIR.mkdir(parents=True, exist_ok=True)
167         ts = datetime.now().strftime("%Y%m%d_%H%M%S")
168         path = REC_DIR / f"session_{ts}.avi" # MJPG/AVI = reliable on Windows
169         fourcc = cv2.VideoWriter_fourcc(*"MJPG")
170         writer = cv2.VideoWriter(str(path), fourcc, 20.0, (w, h))
171         if not writer.isOpened():

```

```

172         return {"error": "Could not open video writer."}
173     _rec.update({"writer": writer, "on": True, "path": path,
174                "frames": 0, "started": time.time()})
175     print(f"[Record] Recording -> {path}")
176     pipeline_state["recording"] = True
177     start_auto() # begin the analyse-every-30s loop
178     return {"ok": True, "path": str(path)}
179
180
181 def stop_recording() -> dict:
182     stop_auto()
183     pipeline_state["recording"] = False
184     with _rec["lock"]:
185         if not _rec["on"]:
186             return {"ok": True, "recording": False}
187         if _rec["writer"] is not None:
188             _rec["writer"].release()
189         n, p = _rec["frames"], _rec["path"]
190         _rec.update({"writer": None, "on": False})
191         print(f"[Record] Saved {n} frames -> {p}")
192         return {"ok": True, "recording": False, "frames": n, "path": str(p)}
193
194
195 # — Auto-analysis loop —————
196
197 def _projecting_now() -> bool:
198     """True while an overlay is on the projector (loop pauses; resumes on Blank)."""
199     return proj.get("mode") == "overlay"
200
201
202 def _auto_wait(seconds: float) -> None:
203     """Sleep up to `seconds`, returning early only if recording stops."""
204     end = time.time() + seconds
205     while time.time() < end:
206         if not (_rec["on"] and _auto["on"]):
207             return
208         time.sleep(0.4)
209
210
211 def auto_loop() -> None:
212     print(f"[Auto] loop started (generate a fresh set every {_auto['interval']}s; "
213           "the live projection stays up until you press Refresh)")
214     while _rec["on"] and _auto["on"]:
215         # Keep generating even while an overlay is projected – the new set is staged
216         # and only goes live on Refresh, so the current projection never drops out.
217         if pipeline_state["status"] == "processing":
218             time.sleep(0.4)
219             continue
220         frame = grab_clean_frame() # briefly blanks + restores the projection
221         if frame is None:
222             time.sleep(0.5)
223             continue
224         cv2.imwrite(str(paths["upload"]), frame)
225         pipeline_state["auto_state"] = "analysing"
226         print("[Auto] analysing latest frame...")
227         pipeline_thread(str(paths["upload"])) # synchronous; writes the LATEST set
228         if pipeline_state["status"] == "ready":
229             pipeline_state["auto_state"] = "ready"
230         _auto_wait(_auto["interval"])
231         pipeline_state["auto_state"] = "idle"
232         _auto["on"] = False
233         print("[Auto] loop stopped")
234
235
236 def start_auto() -> None:
237     if _auto["on"]:
238         return
239     _auto["on"] = True
240     pipeline_state["auto"] = True
241     t = threading.Thread(target=auto_loop, daemon=True)
242     _auto["thread"] = t
243     t.start()
244
245
246 def stop_auto() -> None:
247     _auto["on"] = False
248     pipeline_state["auto"] = False
249     pipeline_state["auto_state"] = "idle"
250
251
252 def start_camera_stream(index: int) -> bool:
253     """Open the camera once and continuously read frames into a shared buffer."""
254     if not CV2_AVAILABLE or _cam["run"]:
255         return _cam["run"]
256     print(f"[Camera] Starting continuous stream on index {index}...")
257     cap = cv2.VideoCapture(index, cv2.CAP_DSHOW if hasattr(cv2, "CAP_DSHOW") else 0)
258     if not cap.isOpened():
259         cap = cv2.VideoCapture(index)

```

```

260     if not cap.isOpened():
261         print(f"[Camera] Could not open camera index {index}")
262         return False
263     cap.set(cv2.CAP_PROP_FRAME_WIDTH, 1280)
264     cap.set(cv2.CAP_PROP_FRAME_HEIGHT, 960)
265     try: cap.set(cv2.CAP_PROP_AUTOFOCUS, 1)
266     except Exception: pass
267     _cam.update({"cap": cap, "index": index, "run": True})
268     pipeline_state["camera_available"] = True
269
270     def _open(idx):
271         c = cv2.VideoCapture(idx, cv2.CAP_DSHOW if hasattr(cv2, "CAP_DSHOW") else 0)
272         if not c.isOpened():
273             c = cv2.VideoCapture(idx)
274         if c.isOpened():
275             c.set(cv2.CAP_PROP_FRAME_WIDTH, 1280)
276             c.set(cv2.CAP_PROP_FRAME_HEIGHT, 960)
277             try: c.set(cv2.CAP_PROP_AUTOFOCUS, 1)
278             except Exception: pass
279         return c
280
281     def _loop():
282         cur = cap
283         fails = 0
284         while _cam["run"]:
285             ret, frame = cur.read()
286             if ret and frame is not None:
287                 fails = 0
288                 if CAM_ROTATE_180:
289                     frame = cv2.rotate(frame, cv2.ROTATE_180) # camera mounted upside down
290                 with _cam["lock"]:
291                     _cam["frame"] = frame
292                     if _rec["on"] and _rec["writer"] is not None:
293                         try:
294                             _rec["writer"].write(frame); _rec["frames"] += 1
295                         except Exception:
296                             pass
297             else:
298                 fails += 1
299                 time.sleep(0.03)
300                 # Device stalled (often a stale USB handle after a hard restart) -
301                 # release and reopen so the stream self-heals instead of freezing.
302                 if fails >= 30:
303                     print("[Camera] Read stalled - reopening device...")
304                     try: cur.release()
305                     except Exception: pass
306                     time.sleep(1.0)
307                     cur = _open(_cam["index"])
308                     fails = 0
309                 try: cur.release()
310                 except Exception: pass
311                 print("[Camera] Stream stopped.")
312
313     threading.Thread(target=_loop, daemon=True).start()
314     print("[Camera] Stream live.")
315     return True
316
317 def grab_latest_frame():
318     """Return a copy of the most recent camera frame (or None)."""
319     with _cam["lock"]:
320         return None if _cam["frame"] is None else _cam["frame"].copy()
321
322 def grab_clean_frame(settle: float = 0.8):
323     """Capture a frame of ONLY the drawing - never the projected overlay.
324     Briefly blanks the projector for a clean capture, then RESTORES the previous
325     projection so it doesn't disappear while the next set is generated."""
326     prev_mode = proj.get("mode")
327     prev_overlay = proj.get("overlay_path")
328     if prev_mode == "overlay":
329         proj["mode"] = "black" # brief blank just for the capture
330         time.sleep(settle) # projector clears (~160ms) + fresh frames
331         frame = grab_latest_frame()
332     if prev_mode == "overlay" and prev_overlay:
333         proj["overlay_path"] = prev_overlay
334         proj["mode"] = "overlay" # put the old projection straight back
335     return frame
336
337 def list_cameras() -> list:
338     if not CV2_AVAILABLE:
339         return []
340     if _cam["run"]:
341         return [_cam["index"]] # don't probe while the stream owns the device
342     found = []
343     for i in range(5):
344         cap = cv2.VideoCapture(i)

```

```

348         if cap.isOpened():
349             found.append(i); cap.release()
350     return found
351
352
353 def capture_from_camera(index: int) -> bool:
354     """Save the most recent streamed frame as the current drawing."""
355     if not _cam["run"]:
356         start_camera_stream(index)
357         time.sleep(0.6) # let a frame arrive
358     frame = grab_latest_frame()
359     if frame is None:
360         return False
361     WORK_DIR.mkdir(parents=True, exist_ok=True)
362     cv2.imwrite(str(paths["upload"]), frame)
363     ts = datetime.now().strftime("%Y%m%d_%H%M%S")
364     cv2.imwrite(str(Path.home() / "Desktop" / f"le_magique_capture_{ts}.jpg"), frame)
365     print(f"[Camera] Saved latest frame -> {paths['upload']}")
366     return True
367
368
369 # — Projector (black by default · warped overlay · 4-corner calibration) —
370
371 proj = {
372     "mode": "black", # black | overlay | calib
373     "overlay_path": None, # projection-ready overlay (marks on black)
374     "corners": None, # [[x,y]] x4 TL,TR,BR,BL in projector-canvas px
375     "size": (1280, 720),
376     "sel": 0, # selected corner during calibration
377 }
378 _proj_run = [False]
379
380
381 def _detect_projector_geom():
382     try:
383         import ctypes
384         u = ctypes.windll.user32
385         prim_w = u.GetSystemMetrics(0); prim_h = u.GetSystemMetrics(1)
386         virt_w = u.GetSystemMetrics(78)
387         second_x = prim_w
388         second_w = virt_w - prim_w if virt_w > prim_w else prim_w
389         return second_x, second_w, prim_h
390     except Exception:
391         return 1920, 1280, 720
392
393
394 def _default_corners(pw, ph):
395     mx, my = 0.22, 0.10 # narrower on the sides by default
396     return [[pw*mx, ph*my], [pw*(1-mx), ph*my], [pw*(1-mx), ph*(1-my)], [pw*mx, ph*(1-my)]]
397
398
399 def load_calibration(pw, ph):
400     if CALIB_FILE.exists():
401         try:
402             c = json.loads(CALIB_FILE.read_text(encoding="utf-8")).get("corners")
403             if c and len(c) == 4:
404                 return [[float(x), float(y)] for x, y in c]
405         except Exception as e:
406             print(f"[Projector] calibration load failed: {e}")
407     return _default_corners(pw, ph)
408
409
410 def save_calibration():
411     CALIB_FILE.write_text(json.dumps({"size": proj["size"], "corners": proj["corners"]},
412                                     indent=2), encoding="utf-8")
413     print(f"[Projector] calibration saved -> {CALIB_FILE.name}")
414
415
416 def _find_coeffs(dst, src):
417     """Perspective coeffs mapping output (dst) coords -> source (src) coords."""
418     M = []
419     for (x, y), (X, Y) in zip(dst, src):
420         M.append([x, y, 1, 0, 0, 0, -X*y, -X*y])
421         M.append([0, 0, 0, x, y, 1, -Y*x, -Y*y])
422     A = np.array(M, dtype=float)
423     B = np.array(src, dtype=float).reshape(8)
424     return np.linalg.solve(A, B).tolist()
425
426
427 def to_projection(path):
428     """Turn a marks-on-white overlay into marks-on-black so only the marks emit light.
429     Also flip 180° when the projector is mounted upside down, so the marks land the
430     right way up on the paper (matching the upright, analysed orientation)."""
431     img = Image.open(path).convert("RGB")
432     if PROJ_ROTATE_180:
433         img = img.rotate(180)
434     arr = np.asarray(img).astype(np.int16)
435     white = (arr > 220).all(axis=2)

```



```

436     arr[white] = 0
437     out = Image.fromarray(arr.astype("uint8"), "RGB")
438     p = str(WORK_DIR / "proj_overlay.png"); out.save(p)
439     return p
440
441
442 def _lerp(a, b, t): return (a[0]+(b[0]-a[0])*t, a[1]+(b[1]-a[1])*t)
443
444
445 def _render_projector():
446     pw, ph = proj["size"]
447     corners = proj["corners"]
448     if proj["mode"] == "overlay" and proj["overlay_path"]:
449         try:
450             ov = Image.open(proj["overlay_path"]).convert("RGB")
451             w, h = ov.size
452             coeffs = _find_coeffs(corners, [(0, 0), (w, 0), (w, h), (0, h)])
453             return ov.transform((pw, ph), Image.PERSPECTIVE, coeffs,
454                               Image.BICUBIC, fillcolor=(0, 0, 0))
455         except Exception as e:
456             print(f"[Projector] warp: {e}")
457     canvas = Image.new("RGB", (pw, ph), (0, 0, 0))
458     if proj["mode"] == "calib":
459         d = ImageDraw.Draw(canvas)
460         pts = [tuple(map(int, c)) for c in corners]
461         tl, tr, br, bl = pts
462         for t in (0.25, 0.5, 0.75):
463             # perspective grid
464             d.line([_lerp(tl, bl, t), _lerp(tr, br, t)], fill=(40, 90, 120), width=1)
465             d.line([_lerp(tl, tr, t), _lerp(bl, br, t)], fill=(40, 90, 120), width=1)
466         d.polygon(pts, outline=(60, 200, 255), width=3)
467         for i, (x, y) in enumerate(pts):
468             col = (255, 90, 90) if i == proj["sel"] else (60, 200, 255)
469             d.ellipse([x-16, y-16, x+16, y+16], outline=col, width=3)
470             d.line([x-24, y, x+24, y], fill=col, width=2)
471             d.line([x, y-24, x, y+24], fill=col, width=2)
472             d.text((x+20, y+12), ["TL", "TR", "BR", "BL"][i], fill=col)
473     return canvas
474
475 def projector_open():
476     if _proj_run[0]:
477         return
478     sx, sw, sh = _detect_projector_geom()
479     proj["size"] = (sw, sh)
480     if proj["corners"] is None:
481         proj["corners"] = load_calibration(sw, sh)
482
483     def _win():
484         _proj_run[0] = True
485         try:
486             root = tk.Tk()
487             root.title("Le Magique Projector")
488             root.configure(bg="black")
489             root.geometry(f"{sw}x{sh}+{sx}+0")
490             root.overrideredirect(True)
491             root.lift()
492
493             label = tk.Label(root, bg="black")
494             label.pack(fill="both", expand=True)
495
496             def refresh():
497                 try:
498                     photo = ImageTk.PhotoImage(_render_projector())
499                     label.configure(image=photo); label.image = photo
500                 except Exception as e:
501                     print(f"[Projector] {e}")
502                 root.after(160, refresh)
503
504             refresh()
505             root.mainloop()
506         except Exception as e:
507             print(f"[Projector] Window error: {e}")
508         finally:
509             _proj_run[0] = False
510
511     threading.Thread(target=_win, daemon=True).start()
512     print("[Projector] window opened (black)")
513
514
515 def show_on_projector(image_path: str):
516     """Project an overlay (warped onto the calibrated paper quad)."""
517     proj["overlay_path"] = to_projection(image_path)
518     proj["mode"] = "overlay"
519     pipeline_state["projecting"] = image_path
520     projector_open()
521
522
523 # — API key loading (file-based, never printed)

```

```

524
525 API_KEY_FILE_CANDIDATES = [
526     Path(__file__).parent / "gemini_api_key.txt",
527     Path(__file__).parent / ".gemini_api_key",
528     Path.home() / ".gemini_api_key",
529 ]
530
531
532 def load_api_key() -> str:
533     """
534     Resolve the Gemini API key without printing it. Priority:
535     1. GEMINI_API_KEY env var
536     2. file path in GEMINI_API_KEY_FILE
537     3. default key file next to the scripts (gemini_api_key.txt / .gemini_api_key)
538     """
539     key = os.getenv("GEMINI_API_KEY")
540     if key and key.strip():
541         return key.strip()
542
543     candidates = []
544     env_path = os.getenv("GEMINI_API_KEY_FILE")
545     if env_path:
546         candidates.append(Path(env_path).expanduser())
547     candidates += API_KEY_FILE_CANDIDATES
548
549     for p in candidates:
550         try:
551             if p and p.is_file():
552                 raw = p.read_text(encoding="utf-8").strip()
553                 first = raw.splitlines()[0] if raw else ""
554                 if "=" in first and "key" in first.lower():
555                     raw = first.split("=", 1)[1]
556                     k = raw.strip().strip('\'').strip('\"')
557                     if k:
558                         return k
559             except Exception:
560                 continue
561     return ""
562
563
564 def has_api_key() -> bool:
565     return bool(load_api_key())
566
567
568 # — Helpers —————
569
570 def build_full_overlay(orig: Image.Image, marks: Image.Image) -> Image.Image:
571     base = orig.convert("RGB").copy()
572     arr = np.array(marks)
573     white = (arr[:, :, 0] > 240) & (arr[:, :, 1] > 240) & (arr[:, :, 2] > 240)
574     mask = Image.fromarray(np.where(white, 0, 255).astype(np.uint8), mode="L")
575     base.paste(marks, mask=mask)
576     return base
577
578
579 # — Pipeline thread —————
580
581 def _merge_marks(a, b):
582     """Overlay marks-image b's non-white pixels onto a (both marks-on-white)."""
583     aa = np.asarray(a.convert("RGB")); bb = np.asarray(b.convert("RGB"))
584     bw = (bb > 240).all(axis=2)
585     out = aa.copy(); out[bw] = bb[~bw]
586     return Image.fromarray(out, "RGB")
587
588
589 def pipeline_thread(image_path: str):
590     def up(step, pct, **kw):
591         pipeline_state.update({"step": step, "progress": pct, **kw})
592
593     api_key = load_api_key()
594     if not api_key:
595         pipeline_state.update({"status": "error",
596                                "error": "No Gemini API key found (set GEMINI_API_KEY, "
597                                         "GEMINI_API_KEY_FILE, or add gemini_api_key.txt)."})
598         return
599     if not PIPELINE_OK:
600         pipeline_state.update({"status": "error",
601                                "error": "drawing_edit_pipeline not available – run from the project folder."})
602         return
603
604     try:
605         pipeline_state["overlays_ready"] = {"full": False, "good_cop": False, "bad_cop": False, "wild_cop": False}
606         up("Loading image", 5, status="processing")
607
608         # Normalise the input to a stable path so output filenames are predictable.
609         src = Path(image_path)
610         img_path = WORK_DIR / "current_drawing.jpg"
611         Image.open(src).convert("RGB").save(str(img_path), "JPEG", quality=95)

```

```

612     stem = img_path.stem # "current_drawing"
613
614     # — Run the EXACT same pipeline the Le Magique dashboard uses —————
615     # Single source of truth: drawing_edit_pipeline.run_pipeline. This keeps
616     # the controller's overlays byte-for-byte consistent with the dashboard
617     # (same prompts, same full-resolution input, same mark extraction).
618     up("Analysing & generating overlays (Le Magique)...", 20)
619     result = dep_run_pipeline(
620         image_path=str(img_path),
621         age_group="unknown",
622         out_dir=str(WORK_DIR),
623     )
624     analysis = result.get("analysis")
625     if not analysis:
626         pipeline_state.update({"status": "error", "error": "Analysis failed – try again."})
627         return
628
629     paths["analysis"].write_text(json.dumps(analysis, indent=2, ensure_ascii=False))
630     fh = analysis.get("feedback_hooks", {})
631
632     # — Map run_pipeline's marks-on-white outputs to the projector overlays —
633     up("Preparing overlays...", 90)
634     out_map = {
635         "good_cop": WORK_DIR / f"{stem}_1_good_cop.png",
636         "bad_cop": WORK_DIR / f"{stem}_2_bad_cop.png",
637         "wild_cop": WORK_DIR / f"{stem}_3_wild_cop.png",
638     }
639     marks = {}
640     for key, p in out_map.items():
641         if p.exists():
642             m = Image.open(p).convert("RGB")
643             m.save(str(paths[key]))
644             marks[key] = m
645             pipeline_state["overlays_ready"][key] = True
646
647     # Laptop-view composites: the drawing WITH each overlay's marks on top,
648     # so the marks can be reviewed on the laptop (no physical paper needed).
649     orig = Image.open(img_path).convert("RGB")
650     combined = None
651     for key in ("good_cop", "bad_cop", "wild_cop"):
652         m = marks.get(key)
653         if m is None: continue
654         if m.size != orig.size: m = m.resize(orig.size, Image.LANCZOS)
655         build_full_overlay(orig, m).save(str(paths["comp_"+key])) # per-personality
656         combined = m if combined is None else _merge_marks(combined, m)
657     if combined is not None:
658         build_full_overlay(orig, combined).save(str(paths["full"])) # all three together
659         pipeline_state["overlays_ready"]["full"] = True
660
661     up("Done", 100, status="ready",
662         gen_id=pipeline_state.get("gen_id", 0) + 1, # bumps each new overlay set
663         age_group=analysis.get("inferred_age_group"),
664         theme=analysis.get("themes", {}).get("primary_theme", ""),
665         mood=analysis.get("emotions", {}).get("overall_mood", ""),
666         tct=analysis.get("tct_dp_score", {}).get("tct_dp_total", 0),
667         engagement_trigger=fh.get("engagement_trigger", ""),
668         good_cop_suggestions=result.get("good_cop_desc") or (fh.get("drawable_additions") or [])[3],
669         bad_cop_suggestions=result.get("bad_cop_desc") or (fh.get("drawable_improvements") or [])[3],
670         wild_cop_suggestions=result.get("wild_cop_desc") or (fh.get("wild_suggestions") or [])[3])
671
672     # First set (or whenever nothing is being projected) goes LIVE immediately so
673     # it's projectable. If an overlay is currently projected, stage this set behind
674     # Refresh so the live projection doesn't change underneath the child.
675     first_set = not any(pipeline_state["active_ready"].values())
676     projecting = pipeline_state.get("current_projection") is not None
677     if first_set or not projecting:
678         commit_active()
679         pipeline_state["pending_refresh"] = False
680     else:
681         pipeline_state["pending_refresh"] = True
682         print("[Active] new set staged – awaiting Refresh")
683     print("[Pipeline] Complete (run_pipeline / Le Magique)")
684
685 except Exception as e:
686     import traceback; traceback.print_exc()
687     pipeline_state.update({"status": "error", "error": str(e)})
688
689 # — Flask routes —————
690
691 app = Flask(__name__)
692
693 @app.route("/")
694 def index():
695     return HTML_PAGE
696
697 @app.route("/upload", methods=["POST"])
698 def upload():

```

```

700     if "file" not in request.files:
701         return jsonify({"error": "No file"}), 400
702     request.files["file"].save(str(paths["upload"]))
703     pipeline_state.update({
704         "status": "idle", "step": "Image uploaded", "progress": 0, "error": "",
705         "overlays_ready": {"full": False, "good_cop": False, "bad_cop": False, "wild_cop": False}
706     })
707     return jsonify({"ok": True})
708
709 @app.route("/capture", methods=["POST"])
710 def capture():
711     if not CV2_AVAILABLE:
712         return jsonify({"error": "OpenCV not installed. Run: pip install opencv-python"}), 400
713     idx = request.json.get("camera_index", CAMERA_INDEX) if request.json else CAMERA_INDEX
714     ok = capture_from_camera(idx)
715     if not ok:
716         cams = list_cameras()
717         return jsonify({"error": f"Capture failed. Try camera index: {cams}"}), 400
718     pipeline_state.update({
719         "status": "idle", "step": "Photo captured", "progress": 0, "error": "",
720         "overlays_ready": {"full": False, "good_cop": False, "bad_cop": False, "wild_cop": False}
721     })
722     return jsonify({"ok": True})
723
724 @app.route("/cameras")
725 def cameras():
726     return jsonify({"cameras": list_cameras(), "cv2": CV2_AVAILABLE})
727
728
729 @app.route("/debug/capture", methods=["POST"])
730 def debug_capture():
731     """Test capture — saves photo and returns confirmation without running pipeline."""
732     if not CV2_AVAILABLE:
733         return jsonify({"error": "OpenCV not installed"}), 400
734     data = request.json or {}
735     index = data.get("camera_index", CAMERA_INDEX)
736     ok = capture_from_camera(index)
737     if not ok:
738         cams = list_cameras()
739         return jsonify({"error": f"Capture failed. Available: {cams}"}), 400
740     size = paths["upload"].stat().st_size if paths["upload"].exists() else 0
741     return jsonify({
742         "ok": True,
743         "path": str(paths["upload"]),
744         "bytes": size,
745         "msg": f"Photo saved ({size//1024}KB). Check le_magique_outputs/ on Desktop."
746     })
747
748 @app.route("/run", methods=["POST"])
749 def run():
750     if pipeline_state["status"] == "processing":
751         return jsonify({"error": "Already processing."}), 400
752     # Capture only the drawing — blank the projector first so the analysis never
753     # sees its own projected marks. Falls back to an uploaded image.
754     frame = grab_clean_frame()
755     if frame is not None:
756         cv2.imwrite(str(paths["upload"]), frame)
757     elif not paths["upload"].exists():
758         return jsonify({"error": "No image. Connect the camera or upload first."}), 400
759     threading.Thread(target=pipeline_thread, args=(str(paths["upload"]),), daemon=True).start()
760     return jsonify({"ok": True})
761
762
763 @app.route("/video_feed")
764 def video_feed():
765     def gen():
766         boundary = b"--frame\r\nContent-Type: image/jpeg\r\n\r\n"
767         while True:
768             f = grab_latest_frame()
769             if f is None:
770                 time.sleep(0.05); continue
771             ok, buf = cv2.imencode(".jpg", f, [cv2.IMWRITE_JPEG_QUALITY, 78])
772             if ok:
773                 yield boundary + buf.tobytes() + b"\r\n"
774             time.sleep(0.045)
775     if not CV2_AVAILABLE:
776         return "No camera", 404
777     return Response(gen(), mimetype="multipart/x-mixed-replace; boundary=frame")
778
779 @app.route("/record/start", methods=["POST"])
780 def record_start():
781     r = start_recording()
782     return (jsonify(r), 400) if r.get("error") else jsonify(r)
783
784 @app.route("/record/stop", methods=["POST"])
785 def record_stop():
786     return jsonify(stop_recording())
787

```

```

788 @app.route("/record/status")
789 def record_status():
790     dur = (time.time() - _rec["started"]) if (_rec["on"] and _rec["started"]) else 0
791     return jsonify({"recording": _rec["on"], "frames": _rec["frames"],
792                    "seconds": round(dur, 1),
793                    "path": str(_rec["path"]) if _rec["path"] else None})
794
795 @app.route("/status")
796 def status():
797     return jsonify(pipeline_state)
798
799 @app.route("/image/<name>")
800 def get_image(name):
801     key = name.replace("-", "_")
802     p = paths.get(key)
803     if p and Path(p).exists():
804         mime = "image/jpeg" if str(p).endswith(".jpg") else "image/png"
805         try:
806             return send_file(str(p), mimetype=mime)
807         except Exception as e:
808             return f"Error: {e}", 500
809     return "Not ready yet", 404
810
811 @app.route("/image/upload/preview")
812 def preview():
813     p = Path(paths["upload"])
814     if p.exists() and p.stat().st_size > 0:
815         try:
816             return send_file(str(p), mimetype="image/jpeg")
817         except Exception as e:
818             return f"Error: {e}", 500
819     return "Not ready yet", 404
820
821 @app.route("/project/<overlay_type>", methods=["POST"])
822 def project(overlay_type):
823     key = overlay_type.replace("-", "_")
824     p = paths.get("active_" + key) # project from the ACTIVE buffer
825     if not p or not Path(p).exists():
826         return jsonify({"error": f"Overlay not ready: {overlay_type}"}, 400)
827     if not TK_AVAILABLE:
828         return jsonify({"error": "tkinter not available on this system."}, 400)
829     show_on_projector(str(p))
830     pipeline_state["current_projection"] = key
831     return jsonify({"ok": True, "projecting": overlay_type})
832
833 @app.route("/project/refresh", methods=["POST"])
834 def project_refresh():
835     """Swap the projection to the freshly-generated set. If none is staged, keep the
836     current projection exactly as it is (never blanks / never loses the last one)."""
837     if not pipeline_state["pending_refresh"]:
838         return jsonify({"ok": True, "refreshed": False,
839                        "msg": "No new overlays yet - keeping the current projection."})
840     commit_active()
841     pipeline_state["pending_refresh"] = False
842     cur = pipeline_state.get("current_projection")
843     if cur and Path(paths["active_" + cur]).exists() and TK_AVAILABLE:
844         show_on_projector(str(paths["active_" + cur])) # re-project same personality, new art
845         return jsonify({"ok": True, "refreshed": True, "projecting": cur})
846     return jsonify({"ok": True, "refreshed": True})
847
848 @app.route("/project/clear", methods=["POST"])
849 def project_clear():
850     proj["mode"] = "black"
851     proj["overlay_path"] = None
852     pipeline_state["projecting"] = None
853     pipeline_state["current_projection"] = None
854     return jsonify({"ok": True})
855
856 # — Projector calibration (4-corner warp onto the paper) —————
857
858 @app.route("/calibrate/start", methods=["POST"])
859 def calib_start():
860     if not TK_AVAILABLE:
861         return jsonify({"error": "tkinter not available."}, 400)
862     proj["mode"] = "calib"; proj["sel"] = 0
863     projector_open()
864     return jsonify({"ok": True, "corners": proj["corners"], "size": proj["size"], "sel": proj["sel"]})
865
866 @app.route("/calibrate/select", methods=["POST"])
867 def calib_select():
868     proj["sel"] = int((request.json or {}).get("corner", 0)) % 4
869     return jsonify({"ok": True, "sel": proj["sel"]})
870
871 @app.route("/calibrate/nudge", methods=["POST"])
872 def calib_nudge():
873     d = request.json or {}
874     dx = float(d.get("dx", 0)); dy = float(d.get("dy", 0))

```



```

876     pw, ph = proj["size"]; c = proj["corners"][proj["sel"]]
877     c[0] = max(0, min(pw, c[0] + dx)); c[1] = max(0, min(ph, c[1] + dy))
878     return jsonify({"ok":True, "corners":proj["corners"]})
879
880 @app.route("/calibrate/scale", methods=["POST"])
881 def calib_scale():
882     d = request.json or {}
883     sx = float(d.get("sx", 1.0)); sy = float(d.get("sy", 1.0))
884     pw, ph = proj["size"]; C = proj["corners"]
885     ccx = sum(p[0] for p in C) / 4.0; ccy = sum(p[1] for p in C) / 4.0
886     for p in C:
887         p[0] = max(0, min(pw, ccx + (p[0]-ccx)*sx))
888         p[1] = max(0, min(ph, ccy + (p[1]-ccy)*sy))
889     return jsonify({"ok":True, "corners":C})
890
891 @app.route("/calibrate/save", methods=["POST"])
892 def calib_save():
893     save_calibration()
894     proj["mode"] = "black"
895     return jsonify({"ok":True})
896
897 @app.route("/calibrate/reset", methods=["POST"])
898 def calib_reset():
899     pw, ph = proj["size"]; proj["corners"] = _default_corners(pw, ph)
900     return jsonify({"ok":True, "corners":proj["corners"]})
901
902 @app.route("/calibrate/stop", methods=["POST"])
903 def calib_stop():
904     proj["mode"] = "black"
905     return jsonify({"ok":True})
906
907
908 # — HTML UI —————
909
910 HTML_PAGE = """<!DOCTYPE html>
911 <html lang="en">
912 <head>
913 <meta charset="UTF-8">
914 <meta name="viewport" content="width=device-width,initial-scale=1">
915 <title>Le Magique — Drawing Co-Bot</title>
916 <link href="https://fonts.googleapis.com/css2?family=DM+Serif+Display:ital@0;1&family=DM+Sans:opsz,wght@9..40,300;9.
917 .40,400;9..40,500&display=swap" rel="stylesheet">
918 <style>
919 *{box-sizing:border-box;margin:0;padding:0}
920 :root{
921   --bg:#0d0d10;--s1:#16161a;--s2:#1e1e24;--bd:#28282f;
922   --green:#3ecf6e;--gd:#163324;--red:#f05252;--rd:#301515;
923   --text:#ededf2;--muted:#6e6e82;--acc:#7c6af7;--acc2:#5a4fd4;
924 }
925 body{background:var(--bg);color:var(--text);font-family:'DM Sans',sans-serif;min-height:100vh}
926 header{padding:1.4rem 1.75rem;border-bottom:1px solid var(--bd);display:flex;align-items:center;gap:12px;position:st
927 icky;top:0;background:var(--bg);z-index:10}
928 .hlogo{width:32px;height:32px;border-radius:8px;background:var(--acc);display:flex;align-items:center;justify-conten
929 t:center;font-size:16px;flex-shrink:0}
930 .htitle{font-family:'DM Serif Display',serif;font-size:18px;letter-spacing:-.2px}
931 .hsub{font-size:11px;color:var(--muted);margin-top:1px}
932 .hright{margin-left:auto;display:flex;align-items:center;gap:8px}
933 .cam-badge{font-size:11px;padding:3px 9px;border-radius:99px;border:1px solid var(--bd);color:var(--muted)}
934 .cam-badge.ok{border-color:var(--green);color:var(--green)}
935
936 .grid{display:grid;grid-template-columns:320px 1fr 260px;gap:0;height:calc(100vh - 61px);overflow:hidden}
937 .col{overflow-y:auto;padding:1.5rem;border-right:1px solid var(--bd)}
938 .col:last-child{border-right:none}
939
940 .ey{font-size:10px;font-weight:500;letter-spacing:.1em;text-transform:uppercase;color:var(--muted);margin-bottom:10p
941 x}
942
943 /* Upload */
944 .upload-zone{border:1.5px dashed var(--bd);border-radius:12px;padding:1.5rem;text-align:center;cursor:pointer;positi
945 on:relative;background:var(--s1);transition:border-color .15s;margin-bottom:12px}
946 .upload-zone:hover,.upload-zone.drag{border-color:var(--acc)}
947 .upload-zone input{position:absolute;inset:0;opacity:0;cursor:pointer;width:100%;height:100%}
948 .upload-zone .ic{font-size:24px;opacity:.35;margin-bottom:8px}
949 .upload-zone p{font-size:12px;color:var(--muted)}
950
951 /* Camera */
952 .cam-btn{width:100%;height:38px;border-radius:9px;background:var(--s2);border:1px solid var(--bd);color:var(--text);
953 font-family:'DM Sans',sans-serif;font-size:12px;cursor:pointer;margin-bottom:12px;display:flex;align-items:center;
954 justify-content:center;gap:7px;transition:all .15s}
955 .cam-btn:hover{background:var(--bd)}
956 .cam-btn.disabled{opacity:.35;cursor:not-allowed}
957
958 .preview{border-radius:10px;overflow:hidden;background:var(--s1);border:1px solid var(--bd);min-height:160px;display
959 :flex;align-items:center;justify-content:center;margin-bottom:12px}
960 .preview img{max-width:100%;max-height:220px;display:block}
961 .preview-ph{font-size:12px;color:var(--muted);padding:2rem;text-align:center}
962
963 .run-btn{width:100%;height:44px;border-radius:10px;font-family:'DM Sans',sans-serif;font-size:13px;font-weight:500;c

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        cursor:pointer;border:none;transition:all .15s;margin-bottom:10px}
956 .run-btn.idle{background:var(--acc);color:#fff}
957 .run-btn.idle:hover{background:var(--acc2)}
958 .run-btn.busy{background:var(--s2);color:var(--muted);cursor:not-allowed}
959 .run-btn.done{background:var(--s2);color:var(--green);border:1px solid #1e5c35}
960
961 .pb{height:3px;background:var(--s2);border-radius:99px;overflow:hidden;margin-bottom:7px}
962 .pf{height:100%;background:var(--acc);border-radius:99px;transition:width .4s}
963 .ps{font-size:11px;color:var(--muted);display:flex;align-items:center;gap:6px}
964 .dot{width:6px;height:6px;border-radius:50%;background:var(--muted);flex-shrink:0}
965 .dot.busy{background:#f5a623;animation:p 1s infinite}
966 .dot.done{background:var(--green)}
967 .dot.error{background:var(--red)}
968 @keyframes p{0%,100%{opacity:1}50%{opacity:.2}}
969
970 .err{background:#1a0808;border:1px solid var(--red);border-radius:9px;padding:10px 12px;font-size:12px;color:var(--red);margin-top:8px;display:none}
971 .err.show{display:block}
972
973 /* Analysis tiles */
974 .atiles{display:grid;grid-template-columns:1fr 1fr;gap:7px;margin-top:14px}
975 .atile{background:var(--s2);border-radius:9px;padding:9px 11px;border:1px solid var(--bd)}
976 .al{font-size:10px;color:var(--muted);margin-bottom:4px}
977 .av{font-size:15px;font-weight:500}
978
979 /* Middle: overlay preview */
980 .overlay-header{display:flex;align-items:center;justify-content:space-between;margin-bottom:10px}
981 .overlay-lbl{font-size:12px;color:var(--muted)}
982 .clear-btn{font-size:11px;padding:3px 9px;border-radius:99px;background:var(--s2);border:1px solid var(--bd);color:var(--muted);cursor:pointer}
983 .clear-btn:hover{color:var(--text)}
984 .overlay-frame{border-radius:12px;overflow:hidden;background:var(--s1);border:1px solid var(--bd);min-height:300px;display:flex;align-items:center;justify-content:center;margin-bottom:14px}
985 .overlay-frame img{max-width:100%;max-height:440px;display:block}
986 .overlay-ph{font-size:12px;color:var(--muted);text-align:center;padding:3rem 2rem;line-height:1.8}
987
988 /* Big overlay buttons */
989 .obtn-wrap{display:grid;grid-template-columns:1fr 1fr 1fr;gap:8px;margin-bottom:14px}
990 .obtn-wrap.four{grid-template-columns:1fr 1fr}
991 .obtn.blank{background:var(--s2);color:var(--text);border:1px solid var(--bd)}
992 .obtn.blank:hover:not(:disabled){background:#222;transform:translateY(-1px)}
993 .rec-row{display:flex;align-items:center;gap:10px;margin:0 0 4px}
994 .rec-btn{height:34px;padding:0 14px;border-radius:9px;border:1px solid var(--bd);background:var(--s2);color:var(--text);font-size:12px;cursor:pointer;display:flex;align-items:center;gap:6px;transition:all .15s}
995 .rec-btn:hover{background:#222}
996 .rec-btn.on{background:#3a1414;border-color:#5c1e1e;color:#ff6b6b}
997 .rec-status{font-size:11px;color:var(--muted)}
998 .rec-status.on{color:#ff6b6b}
999 .obtn{height:56px;border-radius:12px;font-family:'DM Serif Display',serif;font-size:14px;cursor:pointer;border:none;transition:all .15s;display:flex;align-items:center;justify-content:center;gap:6px;letter-spacing:-.2px}
1000 .obtn.good{background:var(--gd);color:var(--green);border:1px solid #1e5c35}
1001 .obtn.good:hover:not(:disabled){background:#1c4530;transform:translateY(-1px);box-shadow:0 4px 16px rgba(62,207,110,.15)}
1002 .obtn.bad{background:var(--rd);color:var(--red);border:1px solid #5c1e1e}
1003 .obtn.bad:hover:not(:disabled){background:#451818;transform:translateY(-1px);box-shadow:0 4px 16px rgba(240,82,82,.15)}
1004 .obtn.wild{background:#2a1840;color:#cc7dff;border:1px solid #4a2a6e}
1005 .obtn.wild:hover:not(:disabled){background:#36205a;transform:translateY(-1px);box-shadow:0 4px 16px rgba(204,125,255,.15)}
1006 .obtn.disabled{opacity:.3;cursor:not-allowed}
1007 .obtn.active{box-shadow:0 0 0 2px currentColor!important}
1008
1009 /* Project button */
1010 .proj-btn{width:100%;height:42px;border-radius:10px;font-family:'DM Sans',sans-serif;font-size:13px;font-weight:500;cursor:pointer;border:none;background:var(--acc);color:#fff;transition:all .15s;margin-bottom:8px;display:flex;align-items:center;justify-content:center;gap:7px}
1011 .proj-btn:hover:not(:disabled){background:var(--acc2)}
1012 .proj-btn.disabled{opacity:.35;cursor:not-allowed}
1013 .proj-status{font-size:11px;color:var(--muted);text-align:center}
1014 .proj-status.on{color:var(--acc)}
1015 .proj-btn.refresh{background:var(--s2);color:var(--text);border:1px solid var(--bd)}
1016 .proj-btn.refresh:hover:not(:disabled){background:#222}
1017 .proj-btn.refresh.ready{background:#0e3a24;color:#3ecf6e;border:1px solid #1e5c35;animation:pulseR 1.4s infinite}
1018 @keyframes pulseR{0%,100%{box-shadow:0 0 0 rgba(62,207,110,.0)}50%{box-shadow:0 0 3px rgba(62,207,110,.25)}}
1019
1020 /* Right: suggestions */
1021 .sug-block{background:var(--s1);border:1px solid var(--bd);border-radius:10px;padding:12px;margin-bottom:10px}
1022 .sug-h{font-size:11px;font-weight:500;letter-spacing:.06em;text-transform:uppercase;margin-bottom:9px;display:flex;align-items:center;gap:6px}
1023 .sug-h.g{color:var(--green)}.sug-h.r{color:var(--red)}
1024 .sug-item{font-size:11px;color:var(--muted);padding:4px 0;border-bottom:1px solid var(--bd);line-height:1.5}
1025 .sug-item:last-child{border:none}
1026 .sug-item:before{content:"· ";color:inherit;opacity:.5}
1027 .nudge{background:linear-gradient(135deg,#13132a,#0f1a2e);border:1px solid #222240;border-radius:10px;padding:11px 13px;font-size:11px;color:#9090c8;line-height:1.7;margin-top:4px}
1028 .nudge strong{color:#aaaae8}
1029
1030 .cbtn{height:36px;border-radius:8px;border:1px solid var(--bd);background:var(--s2);color:var(--text);cursor:pointer}

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;font-size:13px;transition:all .12s}
1031 .cbtn:hover{background:var(--bd)}
1032 .cbtn.sel{border-color:var(--acc);color:var(--acc);background:rgba(91,140,255,.12)}
1033 .livewrap{border-radius:12px;overflow:hidden;background:#000;border:1px solid var(--bd);margin-bottom:8px;aspect-rat
io:4/3;display:flex;align-items:center;justify-content:center}
1034 .livewrap img{width:100%;height:100%;object-fit:contain;display:block}
1035 @media(max-width:900px){.grid{grid-template-columns:1fr;height:auto}.col{border-right:none;border-bottom:1px solid v
ar(--bd)}}
1036 </style>
1037 </head>
1038 <body>
1039 <header>
1040 <div class="hlogo"> </div>
1041 <div><p class="htitle">Le Magique</p><p class="hsub">Drawing Co-Bot · Camera + Projector Controller</p></div>
1042 <div class="hright">
1043 <span class="cam-badg" id="camBadg">Checking camera...</span>
1044 </div>
1045 </header>
1046
1047 <div class="grid">
1048
1049 <!-- COL 1: Input -->
1050 <div class="col">
1051 <p class="ey" style="margin-bottom:10px">Drawing input</p>
1052
1053 <div class="livewrap">
1054 
1056 <div id="liveOff" style="display:none;color:var(--muted);font-size:12px;padding:2rem;text-align:center">Camera
not available – upload an image below</div>
1057 </div>
1058 <p style="font-size:11px;color:var(--muted);margin:0 0 8px">Live camera – <strong style="color:var(--text)">Anal
yse</strong> captures the current frame.</p>
1059
1060 <div class="rec-row">
1061 <button class="rec-btn" id="recBtn" onclick="toggleRecord()">● Record video</button>
1062 <span class="rec-status" id="recStatus">Not recording</span>
1063 </div>
1064 <p style="font-size:10.5px;color:var(--muted);margin:0 0 12px">Saves to <strong style="color:var(--text)">Deskto
p/le_magique_recordings/</strong> for a time-lapse later.</p>
1065
1066 <div class="upload-zone" id="dz" style="padding:14px">
1067 <input type="file" id="fi" accept="image/*">
1068 <p style="margin:0;font-size:11px">Or drop / click to upload an image instead</p>
1069 </div>
1070 <div class="preview" id="preview" style="display:none"></div>
1071
1072 <button class="run-btn idle" id="runBtn" onclick="doRun()">
1073 Analyse current frame + Generate
1074 </button>
1075 <div class="pb"><div class="pf" id="pf" style="width:0"></div></div>
1076 <div class="ps"><span class="dot" id="sdot"></span><span id="stext">Idle</span></div>
1077 <div class="err" id="errBox"></div>
1078
1079 <div id="atiles" style="display:none">
1080 <p class="ey" style="margin-top:16px;margin-bottom:10px">Analysis</p>
1081 <div class="atiles">
1082 <div class="atile"><div class="al">Age group</div><div class="av" id="aAge">—</div></div>
1083 <div class="atile"><div class="al">TCT-DP</div><div class="av" id="aTct">—</div></div>
1084 <div class="atile"><div class="al">Mood</div><div class="av" id="aMood">—</div></div>
1085 <div class="atile"><div class="al">Theme</div><div class="av" id="aTheme" style="font-size:11px;padding-top:
2px">—</div></div>
1086 </div>
1087 </div>
1088 </div>
1089
1090 <!-- COL 2: Overlay preview + projection buttons -->
1091 <div class="col">
1092 <div class="overlay-header">
1093 <p class="ey" style="margin:0">Overlay preview <span style="color:var(--muted);font-weight:400">(on laptop)</s
pan></p>
1094 </div>
1095
1096 <div class="overlay-frame" id="overlayFrame">
1097 <div class="overlay-ph">
1098 Run the pipeline to generate the overlays.<br>
1099 The drawing with its suggestions appears here,<br>
1100 and the buttons below send each to the projector.
1101 </div>
1102 </div>
1103
1104 <p class="ey" style="margin:2px 0 8px;font-size:11px">Send to projector</p>
1105 <div class="obtn-wrap four">
1106 <button class="obtn good" id="projGood" onclick="projectOverlay('good_cop')" disabled> Additions</button>
1107 <button class="obtn bad" id="projBad" onclick="projectOverlay('bad_cop')" disabled> Realism</button>
1108 <button class="obtn wild" id="projWild" onclick="projectOverlay('wild_cop')" disabled> Imagination</button>
1109 <button class="obtn blank" id="projBlank" onclick="projectBlank()"> Blank screen</button>
1110 </div>

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1111 <button class="proj-btn refresh" id="refreshBtn" onclick="refreshProjection()" disabled>
1112   Refresh projection
1113 </button>
1114 <p class="proj-status" id="projStatus">Projector: showing blank</p>
1115
1116 <div style="margin-top:18px;border-top:1px solid var(--bd);padding-top:14px">
1117   <p class="ey" style="margin-bottom:8px">Projector alignment</p>
1118   <button class="proj-btn" id="calibBtn" onclick="calibToggle()"
1119     style="background:var(--s2);color:var(--text);border:1px solid var(--bd)">Calibrate on paper</button>
1120   <div id="calibBox" style="display:none">
1121     <p style="font-size:11px;color:var(--muted);line-height:1.6;margin:6px 0 10px">
1122       Pick a corner, nudge it until the projected box lines up with the paper edges, then save.</p>
1123     <div style="display:grid;grid-template-columns:repeat(4,1fr);gap:6px;margin-bottom:10px">
1124       <button class="cbtn" data-c="0" onclick="calibSel(0)">TL</button>
1125       <button class="cbtn" data-c="1" onclick="calibSel(1)">TR</button>
1126       <button class="cbtn" data-c="3" onclick="calibSel(3)">BL</button>
1127       <button class="cbtn" data-c="2" onclick="calibSel(2)">BR</button>
1128     </div>
1129     <div style="display:flex;align-items:center;gap:8px;justify-content:center;margin-bottom:10px">
1130       <span style="font-size:11px;color:var(--muted)">step</span>
1131       <input id="calibStep" type="number" value="10" min="1" max="100"
1132         style="width:58px;height:32px;border-radius:8px;border:1px solid var(--bd);background:var(--s2);col
1133           or:var(--text);text-align:center">
1134       <span style="font-size:11px;color:var(--muted)">px</span>
1135     </div>
1136     <div style="display:grid;grid-template-columns:repeat(3,46px);gap:6px;justify-content:center;margin-bottom:1
1137       2px">
1138       <span></span><button class="cbtn" onclick="calibNudge(0,-1)">↑</button><span></span>
1139       <button class="cbtn" onclick="calibNudge(-1,0)">←</button>
1140       <button class="cbtn" onclick="calibNudge(0,1)">↓</button>
1141       <button class="cbtn" onclick="calibNudge(1,0)">→</button>
1142     </div>
1143     <p style="font-size:11px;color:var(--muted);margin:0 0 6px">Resize whole area</p>
1144     <div style="display:grid;grid-template-columns:1fr 1fr 1fr;gap:6px;margin-bottom:12px">
1145       <button class="cbtn" onclick="calibScale(0.95,1)">↵ Narrower</button>
1146       <button class="cbtn" onclick="calibScale(1,0.95)">⏏ Shorter</button>
1147       <button class="cbtn" onclick="calibScale(0.95,0.95)">↵ Smaller</button>
1148       <button class="cbtn" onclick="calibScale(1.05,1)">↵ Wider</button>
1149       <button class="cbtn" onclick="calibScale(1,1.05)">⏏ Taller</button>
1150       <button class="cbtn" onclick="calibScale(1.05,1.05)">↵ Bigger</button>
1151     </div>
1152     <div style="display:flex;gap:6px">
1153       <button class="proj-btn" style="background:var(--s2);color:var(--text);border:1px solid var(--bd);margin:0
1154         " onclick="calibReset()">Reset</button>
1155       <button class="proj-btn" style="margin:0" onclick="calibSave()">Save & exit</button>
1156     </div>
1157   </div>
1158 </div>
1159 </div>
1160 </div>
1161 <div class="col">
1162   <p class="ey">Suggestions</p>
1163   <div id="sugArea">
1164     <p style="font-size:12px;color:var(--muted)">Run the pipeline to see suggestions here.</p>
1165   </div>
1166 </div>
1167
1168 <script>
1169 let pollTimer = null;
1170
1171 // Check camera on load
1172 fetch('/cameras').then(r=>r.json()).then(d=>{
1173   const b = document.getElementById('camBadge');
1174   if(d.cameras.length > 0){
1175     b.textContent = `C270 live (index ${d.cameras[0]})`;
1176     b.className = 'cam-badge ok';
1177   } else {
1178     b.textContent = 'No camera detected';
1179   }
1180 });
1181
1182 // File upload
1183 const fi = document.getElementById('fi');
1184 const dz = document.getElementById('dz');
1185 fi.addEventListener('change', e => { if(e.target.files[0]) doUpload(e.target.files[0]); });
1186 dz.addEventListener('dragover', e=>{ e.preventDefault(); dz.classList.add('drag'); });
1187 dz.addEventListener('dragleave', ()=>dz.classList.remove('drag'));
1188 dz.addEventListener('drop', e=>{ e.preventDefault(); dz.classList.remove('drag'); if(e.dataTransfer.files[0]) doUplo
1189   ad(e.dataTransfer.files[0]); });
1190
1191 async function doUpload(file){
1192   const fd = new FormData();
1193   fd.append('file', file);
1194   await fetch('/upload', {method:'POST', body:fd});
1195   showPreview(`/image/upload/preview?t=${Date.now()}`);

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```

1195     resetOverlays();
1196 }
1197
1198 async function doCapture(){
1199     const btn = document.getElementById('captureBtn');
1200     btn.disabled = true;
1201     btn.textContent = ' Capturing...';
1202     const r = await fetch('/capture', {method:'POST', headers:{'Content-Type':'application/json'}, body:JSON.stringify({})});
1203     const d = await r.json();
1204     btn.disabled = false;
1205     btn.textContent = ' Capture from C270 webcam';
1206     if(d.error){ showErr(d.error); return; }
1207     showPreview('/image/upload/preview?t=${Date.now()}');
1208     resetOverlays();
1209 }
1210
1211 async function doDebugCapture(){
1212     const btn = document.getElementById('debugBtn');
1213     btn.disabled = true;
1214     btn.textContent = ' Testing...';
1215     const r = await fetch('/debug/capture', {method:'POST', headers:{'Content-Type':'application/json'}, body:JSON.stringify({})});
1216     const d = await r.json();
1217     btn.disabled = false;
1218     btn.textContent = ' Test camera only (no pipeline)';
1219     if(d.error){ showErr(d.error); return; }
1220     showPreview('/image/upload/preview?t=${Date.now()}');
1221     hideErr();
1222     document.getElementById('stext').textContent = d.msg;
1223 }
1224
1225 function showPreview(src){
1226     const wrap = document.getElementById('preview');
1227     const img = new Image();
1228     img.onload = () => {
1229         wrap.innerHTML = ``;
1230         hideErr();
1231     };
1232     img.onerror = () => {
1233         // Retry after 500ms – file might still be writing
1234         setTimeout(() => showPreview(src), 500);
1235     };
1236     img.src = src;
1237 }
1238
1239 async function doRun(){
1240     if(recOn){ return; } // while recording, the auto-loop drives analysis – don't double-trigger
1241     if(document.getElementById('runBtn').classList.contains('busy')) return;
1242     const r = await fetch('/run', {method:'POST'});
1243     const d = await r.json();
1244     if(d.error){ showErr(d.error); return; }
1245     startPoll();
1246 }
1247
1248 function startPoll(){
1249     if(pollTimer) clearInterval(pollTimer);
1250     pollTimer = setInterval(doPoll, 1200);
1251 }
1252
1253 let lastGenId = 0;
1254 async function doPoll(){
1255     const d = await fetch('/status').then(r=>r.json());
1256     const run = document.getElementById('runBtn');
1257     const pf = document.getElementById('pf');
1258     const dot = document.getElementById('sdot');
1259     const st = document.getElementById('stext');
1260
1261     pf.style.width = d.progress+'%';
1262     dot.className = 'dot ' + d.status;
1263
1264     // Projection buttons follow the ACTIVE (projectable) set – they stay usable even
1265     // while a new set is generating, so the live projection never drops out.
1266     const ar = d.active_ready || {};
1267     document.getElementById('projGood').disabled = !ar.good_cop;
1268     document.getElementById('projBad').disabled = !ar.bad_cop;
1269     document.getElementById('projWild').disabled = !ar.wild_cop;
1270     // Refresh: usable once any set is active; glows when a newer set is staged.
1271     const rb = document.getElementById('refreshBtn');
1272     rb.disabled = !(ar.good_cop || ar.bad_cop || ar.wild_cop);
1273     rb.classList.toggle('ready', !!d.pending_refresh);
1274
1275     // Status line.
1276     let label = d.step || d.status;
1277     if(d.recording){
1278         if(d.auto_state==='analysing') label = ' Auto – analysing the drawing..';
1279         else label = ' Recording – new set every 30s';
1280     }

```



```

1281 if(d.pending_refresh){ label = ' New overlays ready – press Refresh to project them'; }
1282 st.textContent = label;
1283
1284 if(d.status === 'processing'){
1285     run.className='run-btn busy';
1286     run.textContent = d.recording ? ' Recording – generating next set...' : 'Generating...';
1287 }
1288
1289 if(d.age_group){
1290     document.getElementById('atiles').style.display='block';
1291     document.getElementById('aAge').textContent = d.age_group;
1292     document.getElementById('aTct').textContent = (d.tct??'-')+'/14';
1293     document.getElementById('aMood').textContent = d.mood||'-';
1294     document.getElementById('aTheme').textContent= (d.theme||'-').slice(0,28);
1295 }
1296
1297 if(d.status==='ready'){
1298     run.className='run-btn done';
1299     run.textContent = d.recording ? ' Recording – overlays auto-refreshing'
1300                     : ' Ready – overlays generated';
1301     renderSuggestions(d);
1302     // Preview the NEWEST analysis on the laptop whenever a fresh set arrives.
1303     if(d.gen_id && d.gen_id!==lastGenId){
1304         lastGenId = d.gen_id;
1305         if(d.overlays_ready.full) showComposite('full');
1306     }
1307     if(!d.recording) clearInterval(pollTimer);
1308 }
1309
1310 if(d.status==='error'){
1311     run.className='run-btn idle';
1312     run.textContent='Retry';
1313     showErr(d.error);
1314     if(!d.recording) clearInterval(pollTimer);
1315 }
1316 }
1317
1318 async function refreshProjection(){
1319     const r = await fetch('/project/refresh', {method:'POST'});
1320     const d = await r.json();
1321     const ps = document.getElementById('projStatus');
1322     if(d.refreshed){
1323         document.getElementById('refreshBtn').classList.remove('ready');
1324         if(d.projecting){
1325             showComposite('active_comp_'+d.projecting);
1326             ps.textContent = `Projecting (updated): ${PROJ_LABELS[d.projecting]}|'|`;
1327             ps.className = 'proj-status on';
1328         } else {
1329             ps.textContent = 'Latest overlays are now live – pick a projection.';
1330             ps.className = 'proj-status on';
1331         }
1332     } else {
1333         ps.textContent = d.msg || 'No new overlays – keeping the current projection.';
1334     }
1335 }
1336
1337 const PROJ_LABELS = {good_cop:' Additions', bad_cop:' Realism', wild_cop:' Imagination'};
1338 const PROJ_BTN = {good_cop:'projGood', bad_cop:'projBad', wild_cop:'projWild'};
1339
1340 // Show the drawing WITH the overlay on the laptop. `type` = 'full' (newest, all marks),
1341 // a personality key (newest composite), or 'active_'+key (the projected composite).
1342 function showComposite(type){
1343     let key;
1344     if(type==='full') key='full';
1345     else if(type.startsWith('active_')) key=type; // e.g. active_comp_good_cop
1346     else key='comp_'+type;
1347     const src = `/image/${key.replace(/_/g, '-')}?t=${Date.now()}`;
1348     const frame = document.getElementById('overlayFrame');
1349     const img = new Image();
1350     img.onload = () => { frame.innerHTML = ``; };
1351     img.onerror = () => { console.log('Composite not ready yet:', type); };
1352     img.src = src;
1353 }
1354
1355 // Project a single overlay (from the ACTIVE set) AND preview that exact set on the laptop.
1356 async function projectOverlay(type){
1357     markActive(PROJ_BTN[type]);
1358     const r = await fetch(`/project/${type.replace('_', '-')}`, {method:'POST'});
1359     const d = await r.json();
1360     const ps = document.getElementById('projStatus');
1361     if(d.error){ ps.textContent = ' ' + d.error; ps.className = 'proj-status'; }
1362     else {
1363         showComposite('active_comp_'+type); // preview matches what's projected
1364         ps.textContent = `Projecting: ${PROJ_LABELS[type]}|'|`; ps.className = 'proj-status on';
1365     }
1366 }
1367
1368 async function projectBlank(){

```

```

1369 markActive('projBlank');
1370 await fetch('/project/clear', {method:'POST'});
1371 // On the laptop, fall back to the full composite (or placeholder) for review.
1372 showComposite('full');
1373 const ps = document.getElementById('projStatus');
1374 ps.textContent = 'Projector: blank screen'; ps.className = 'proj-status';
1375 }
1376
1377 function markActive(id){
1378   ['projGood','projBad','projWild','projBlank'].forEach(b=>
1379     document.getElementById(b).classList.toggle('active', b===id));
1380 }
1381
1382 // — Video recording —
1383 let recOn=false;
1384 async function toggleRecord(){
1385   const url = recOn ? '/record/stop' : '/record/start';
1386   const r = await fetch(url,{method:'POST'});
1387   const d = await r.json();
1388   const btn=document.getElementById('recBtn'), st=document.getElementById('recStatus');
1389   if(d.error){ st.textContent=' '+d.error; return; }
1390   recOn = !recOn;
1391   btn.classList.toggle('on',recOn);
1392   btn.textContent = recOn ? '■ Stop recording' : '● Record video';
1393   st.classList.toggle('on',recOn);
1394   if(recOn){
1395     pollRecord();
1396     startPoll(); // recording also drives the auto-analysis loop – poll continuously
1397   } else {
1398     st.textContent = d.frames!=null ? `Saved ${d.frames} frames` : 'Not recording';
1399   }
1400 }
1401 function pollRecord(){
1402   if(!recOn) return;
1403   fetch('/record/status').then(r=>r.json()).then(d=>{
1404     if(d.recording){
1405       document.getElementById('recStatus').textContent = `● Recording – ${d.seconds}s`;
1406       setTimeout(pollRecord, 1000);
1407     }
1408   });
1409 }
1410
1411 // — Projector calibration —
1412 let calibOn=false, calibSelected=0;
1413 const J={'Content-Type':'application/json'};
1414 function calibToggle(){ calibOn ? calibStop() : calibStart(); }
1415 function calibStart(){
1416   fetch('/calibrate/start',{method:'POST'}).then(r=>r.json()).then(d=>{
1417     if(d.error){ showErr(d.error); return; }
1418     calibOn=true; calibSelected=d.sel||0;
1419     document.getElementById('calibBox').style.display='block';
1420     document.getElementById('calibBtn').textContent='Exit calibration';
1421     markSel();
1422   });
1423 }
1424 function calibStop(){
1425   fetch('/calibrate/stop',{method:'POST'});
1426   calibOn=false;
1427   document.getElementById('calibBox').style.display='none';
1428   document.getElementById('calibBtn').textContent='Calibrate on paper';
1429 }
1430 function calibSel(c){
1431   calibSelected=c;
1432   fetch('/calibrate/select',{method:'POST',headers:J,body:JSON.stringify({corner:c})});
1433   markSel();
1434 }
1435 function markSel(){
1436   document.querySelectorAll('.cbtn[data-c]').forEach(b=>b.classList.toggle('sel',+b.dataset.c===calibSelected));
1437 }
1438 function calibNudge(sx,sy){
1439   const s+=document.getElementById('calibStep').value||10;
1440   fetch('/calibrate/nudge',{method:'POST',headers:J,body:JSON.stringify({dx:sx*s,dy:sy*s})});
1441 }
1442 function calibScale(sx,sy){ fetch('/calibrate/scale',{method:'POST',headers:J,body:JSON.stringify({sx,sy})}); }
1443 function calibReset(){ fetch('/calibrate/reset',{method:'POST'}); }
1444 function calibSave(){
1445   fetch('/calibrate/save',{method:'POST'}).then(()=>{
1446     calibOn=false;
1447     document.getElementById('calibBox').style.display='none';
1448     document.getElementById('calibBtn').textContent='Calibrate on paper';
1449     document.getElementById('projStatus').textContent='Calibration saved ';
1450   });
1451 }
1452
1453 function renderSuggestions(d){
1454   const good = (d.good_cop_suggestions||[]).map(s=><div class="sug-item">${s}</div>`').join('');
1455   const bad = (d.bad_cop_suggestions||[]).map(s=><div class="sug-item">${s}</div>`').join('');
1456   const wild = (d.wild_cop_suggestions||[]).map(s=><div class="sug-item">${s}</div>`').join('');

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1457 const nudge = d.engagement_trigger ? `<div class="nudge"><strong>Nudge:</strong> ${d.engagement_trigger}</div>` :
1458 '';
1459 document.getElementById('sugArea').innerHTML = `
1460 <div class="sug-block">
1461   <div class="sug-h g"> Additions</div>${good||'<div class="sug-item">None</div>'}
1462 </div>
1463 <div class="sug-block">
1464   <div class="sug-h r"> Realism</div>${bad||'<div class="sug-item">None</div>'}
1465 </div>
1466 <div class="sug-block">
1467   <div class="sug-h" style="color:#cc7dff"> Imagination</div>${wild||'<div class="sug-item">None</div>'}
1468 </div>
1469   ${nudge}`;
1470 }
1471 function resetOverlays(){
1472   ['projGood','projBad','projWild'].forEach(id=>{
1473     const b=document.getElementById(id); b.disabled=true; b.classList.remove('active');
1474   });
1475   document.getElementById('projBlank').classList.remove('active');
1476   const rb=document.getElementById('refreshBtn'); rb.disabled=true; rb.classList.remove('ready');
1477   document.getElementById('overlayFrame').innerHTML=`<div class="overlay-ph">Run the pipeline to generate the overla
1478 ys.<br>The drawing with its suggestions appears here.</div>`;
1479   document.getElementById('runBtn').className='run-btn idle';
1480   document.getElementById('runBtn').textContent='Analyse current frame + Generate';
1481   document.getElementById('pf').style.width='0';
1482   document.getElementById('atiles').style.display='none';
1483   document.getElementById('sugArea').innerHTML=`<p style="font-size:12px;color:var(--muted)">Run the pipeline to see
1484 suggestions here.</p>`;
1485   hideErr();
1486 }
1487 function showErr(msg){ const b=document.getElementById('errBox'); b.textContent=` ${msg}; b.className='err show'; }
1488 function hideErr(){ document.getElementById('errBox').className='err'; }
1489 </script>
1490 </body>
1491 </html>""
1492
1493 # — Entry —————
1494
1495 if __name__ == "__main__":
1496     import webbrowser, atexit
1497
1498     atexit.register(stop_recording) # flush any in-progress video on shutdown
1499
1500     parser = argparse.ArgumentParser(description="Le Magique laptop controller.")
1501     parser.add_argument("--camera", type=int, default=0, help="Camera index (default 0).")
1502     parser.add_argument("--port", type=int, default=5000)
1503     parser.add_argument("--master-context", default=None, help="Path to MASTER_CONTEXT.json.")
1504     parser.add_argument("--no-cam-flip", action="store_true", help="Camera is mounted upright (don't rotate 180°).")
1505     parser.add_argument("--no-proj-flip", action="store_true", help="Projector is mounted upright (don't rotate 180°
1506 ).")
1507     args = parser.parse_args()
1508     CAMERA_INDEX = args.camera
1509     if args.no_cam_flip: CAM_ROTATE_180 = False
1510     if args.no_proj_flip: PROJ_ROTATE_180 = False
1511
1512     # Inject explicit master context path if provided
1513     if args.master_context:
1514         mc_path = Path(args.master_context)
1515         if mc_path.exists():
1516             MASTER_CONTEXT_PATHS.insert(0, mc_path)
1517             print(f" Master ctx: {mc_path}")
1518         else:
1519             print(f" [!] --master-context path not found: {mc_path}")
1520
1521     api_key = has_api_key()
1522
1523     print("\n" + "="*52)
1524     print(" Le Magique Laptop Controller – Camera + Projector")
1525     print("="*52)
1526     print(f" API key : {'set ' if api_key else 'NOT SET' – set GEMINI_API_KEY / key file}")
1527     print(f" Camera : index {CAMERA_INDEX} (Logitech C270)")
1528     print(f" Flip : camera {'180' if CAM_ROTATE_180 else 'off'} | projector {'180' if PROJ_ROTATE_180 else 'off'
1529 }")
1530     print(f" Output : {WORK_DIR.absolute()}")
1531     print(f" URL : http://localhost:{args.port}")
1532     print("="*52)
1533     print()
1534     print(" Connect projector via HDMI before clicking 'Send to projector'.")
1535     print(" The overlay will appear fullscreen on the second display.\n")
1536
1537     if not CV2_AVAILABLE:
1538         print(" [!] Install OpenCV for camera support: pip install opencv-python\n")
1539     if not TK_AVAILABLE:
1540         print(" [!] tkinter not available – projector display may not work.\n")

```

```
1539
1540 # Start the continuous camera stream (projector stays dark until you project)
1541 if CV2_AVAILABLE:
1542     start_camera_stream(CAMERA_INDEX)
1543
1544 # Skip the auto browser pop when embedded (e.g. launched by the dashboard).
1545 if not os.getenv("LEMAGIQUE_NO_BROWSER"):
1546     threading.Timer(1.2, lambda: webbrowser.open(f"http://localhost:{args.port}")).start()
1547 app.run(host="0.0.0.0", port=args.port, debug=False)
1548
```