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Sketching Together:

Designing a Co-creative System with a Pen Plotter

Kilian Robert Dennis Vesshoff

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Dr. Nina Wenig
Prof. Dr. Frieder Nake
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Abstract

This thesis addresses the convergence of art and technology through the development of a co-creative drawing system that integrates human input with a pen plotter. The study investigates the optimization of cooperative drawing systems for precise human-robot interaction and examines whether such systems can enhance the creative process and change the perception of authorship in collaborative art. Based on the historical development of pen plotters, important milestones and influential artists in this field are presented. A custom-built Arduino-based pen plotter was developed and tested in the user study, focusing on the dynamics of human-robot collaboration. The results suggest that the addition of a robot as a co-author can enrich the creative process, although challenges remain in terms of software precision and perception of authorship. Future work will aim to overcome these limitations, explore advanced interaction techniques, and develop more robust hardware and software solutions.

The digital repository contains all related data, including the code used, all questionnaires, additional study images, and the resulting images. https://gitlab.informatik.uni-bremen.de/vesshoff/Cocreation-PenPlotter-Thesis

Declaration

I, Kilian Vesshoff, declare that this thesis titled, *Sketching Together: Designing a Co-creative System with a Pen Plotter* and my work is my own. I have acknowledged all the sources of information and literature used.

Signature: ....

Date: ....

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1 Introduction

1.1 Background and Motivation

Since the beginning of my student career, I've been trying to understand the connection between art and computer science; the digital media degree is divided into media design and media informatics. They are easy to understand by themselves, but connecting them never made sense to me. The world of numbers, code, and endless hours in front of screens has ups and downs. The digital art world, made up of video, animations, colourful 3D modelling, and questions about aesthetic and design choices, seems so distant from the informatics. It took a while to see the beauty hiding in the heap of numbers, seeing the complexity of graphs and nodes connected to background datasets fed by other data, a root system with no visible end, and searching my way through it to a leaf. I feel like mycelium reaching out to trees in a forest network, diving deep into the root systems. Once the data and numbers are visualised, the beauty is as clear as the sky. Without visualizing data, It's hard to get a grip on what you are looking at, and if you do it rightly and with purpose, it can be visually pleasing and improve understanding.

Art has never been a big interest of mine, nor do robots seem specifically attractive. But I'm in for it when a pen is attached to a robotic arm flying over the paper and drawing the data I can see on screen. Pen Plotters, to me, are more than printers; seeing the pen move over the paper, leaving a line of black ink that slowly soaks into the paper, is mesmerizing; I find myself watching the pen zip around the paper for hours. The anticipation is to see what it does next, how close it will get to the lines and shapes already on paper, where it will cross another line, and whether it will extend the boundaries of the paper and draw on the table; these questions are constantly on my mind. I feel like everyone who walks past the plotter for the first time can't resist its hypnotic effect, a way of giving digital art a natural feel, the opposite of digitizing.

In 2020, I built my own Pen Plotter, a simple Arduino-based plotter with a small servo that moves the pen up and down and two stepper motors that move the belts around, allowing the pen tip to reach any x-y position on paper. The plotter used in this thesis is the 4th iteration of this original version, faster, more stable, and custom-built for this project. All of that aside, I would not consider myself an artist, and the Plotter is just a tool; it is a way to get from the static program we have in our computers, made up of lines of code in whatever programming language, to a dynamic drawing that then creates a piece of art. This art is haptic, and real, it can be touched, burned, destroyed, or framed and hung up on a wall. Although it depends on what you consider art, artistic perception is biased; the drawings from the Pen Plotter aren't for everyone; the plotter's drawings are one-of-a-kind in their own way. Even when rerunning to the same script, it's possible to have variations due to pen pressure, paper alignment, movement of the machine itself, and so on. When creating my first own art pieces, inspired by the movement, I began creating geometrical patterns from simple shapes to complex overlapping lines to force a morai effect, varying in pens, colours, paper thickness, and size, experiments with scalpels cutting instead of pens drawing, watercolour, and charcoal. Often, it didn't turn out the way I had in mind; I blamed it on the Pen Plotter.

In my free time over the past two years, I wrote code for generative art pieces and other geometrical projects, but it was always me and the robot. To be exact, I always told the robot what to do; the robot drew, and the interaction was done. The idea of co-creating with the robot didn't come to my mind until early 2024. Stumbling over artists such as Sougwen Chung made me think of a system in which humans and robots draw together, simultaneously or after one another. These and many other questions came to my mind: can I develop a system that can do this? Could it be beneficial and supportive of the creation process? Will the resulting art look any good? Will it work with other people? Focusing on the creation process, the concept of co-creation, and the ethics of working with robots, I went to work.

A prototype and a script to control the Pen Plotter were made. But what was I trying to discover? I knew authorship would play a role, with the question being who has the rights to the final art piece and why. The recent explosion of AI, generating images from text prompts, had me thinking if the co-creative interaction takes from the feeling of ownership when creating the human perception of this is essential. I also wanted to know if the system is worth a scientific study. Was the one-sided interaction with the Pen Plotter so bad? Could the Pen Plotter inspire me? Could the system influence my creative process and support me in my making? Will the interaction be enjoyable? Is there a sense of satisfaction when working with the Pen Plotter, maybe in the same way as watching it draw? Maybe not. All this was in my mind during the development process.

1.2 Structure

This paper is organized into six main chapters, each addressing distinct aspects of developing and evaluating a co-creative system. The chapter *Introduction* 1 will provide the background and motivation for the study, outline the research questions and objectives, and discuss the limitations and scope of the research. It sets the stage for understanding the relevance and constraints of the study. Continuing chapter *Literature Context* 2 will present a comprehensive review of existing literature relevant to the field of Pen Plotters and the development of the co-creative study, from the historical development of artists to technological advancement. A broader view of the field of human-robot collaboration and understanding of authorship and the creative process will be given before the chapter of *Cooperation* 3, which explores the different dynamics of human collaborations with each other and robots. As well as the impact robotic systems have on the creative process and drawing specifically.

Chapter *Methodology* 4 gives an insight into the development and design process and provides an overview of the Pen Plotter, conceptual framework, and the development of hardware and software. Followed by the evaluation methods and design of the testing and assessment metrics later used. *Results and Discussion* 5 presents the findings of the said study and discusses their implications, analysis of the data, and art, alongside interpretations of results and key insights. Finally, in *Conclusion and Future Work* 6 summarize all discoveries and reflect the overall contribution with directions for future research, giving an outlook for potential improvements.

1.3 Research Questions and Objective

From a technical perspective, the research Question is: How can the hardware and software of an Arduino-based Pen Plotter be optimized to enhance precision and reliability in tracking and drawing? Considering the limitations and potential for improving mechanical robustness, algorithmic sophistication, and multi-device coordination, how can such a system be effectively integrated into a co-creative environment with a human artist? Alongside the technical challenge, the paper's primary question will be on co-creation: How does the collaboration between a human and an Arduino-based Pen Plotter influence the creative process and outcomes? And what are the implications for authorship and creative ownership in such a co-creative environment?

On the one hand, research into the field of Pen Plotters is largely unexplored. On the other hand, human-robot interactions have seen an increase in interest over the past decade. Chatbots have become the norm for service chats all over the internet, and voice-activated assistants in our mobile phones and independent devices have become useful assistants in day-to-day tasks[36]. This paper explores what a system could look like where a human and a robot collaborate seamlessly to create a physical drawing.

The creative process describes the human's thoughts and behavior when, in this case, drawing something. It's an iterative process of ideas to actions to realizations, and back to actions and new ideas, refining ideas, and their outcome can be massively influenced by the robotic co-creator. Adding a second creator always influences the creative process; it's why we humans work in groups, and bigger tasks can only be tackled with even bigger groups, but having a robot partner adds different elements to the equation[17]. In this case, the robot will act in a way that is previously defined, the plotter will not iterate over thoughts and ideas, it will draw.

In addition to the creative process, there is the issue of ownership and authorship of the final work. When creating a sketch, authorship is generally straightforward: it is clear that the person who had the idea and physically executed the drawing holds the right to claim authorship of the final piece[12]. But what happens when you cooperate with a robotic system developed and built by someone else? The software in the background is written by someone else, and then you even get told what to draw. Do you still hold ownership of what comes out at the end? Providing answers to these questions will be one of the paper's objectives.

Additionally, the development itself will hold many challenges to overcome. The hard- and software must be created and adjusted to the system's specific needs. With little to work on top of it, most will have to be made from scratch. The co-creative system is, therefore, also the objective of this work, the development and conduction of a user study and later evaluation with the research in mind.

1.4 Limitations and Scope

The Pen Plotters used over the development period are by no means professional, they cannot be compared to industrial robotic arms for example from the company KUKA which are used in some projects mentioned in this paper. The Pen Plotter used in this system is fragile; it's built to be customizable and professional but with minimal cost compared to existing models. The version of the Pen Plotter that will be used in this study's testing is built explicitly for the testing environment. The goal is not to construct high-end hardware but to provide a functional system to examine the aspects mentioned before. Considering the building process of the Pen Plotter and the lack of existing software to control the robot, time invested into solutions for this can take its toll on the user study. Overcoming the software challenges and hardware restraints in the development process might limit the quality of the user tests, again the focus is on the interaction and the possibilities of assisting a human in the creation process.

The goal of this study is to evaluate the integration of a Pen Plotter into a co-creative system with a human, focusing on how this collaboration influences the creative process and resulting output. This study does not aim to analyze neural activity or involve sensory attachments; instead, it centers on the interaction between human creativity and robotic assistance using a pen and paper as the only tools provided to the users. By keeping it simple, the focus will lie on what matters, and results will not be influenced by outstanding factors.

The Pen Plotters utilized throughout the development phase are not on par with industrial grade robotic systems, such as those from KUKA. The Pen Plotter used is relatively fragile and less accurate, having been constructed with cost-efficiency in mind.

Many of the Pen Plotters' parts are 3D printed and designed to keep the weight low to allow for lighter motors. It was specifically built for the testing environment of this study, and while it serves as a functional prototype, it lacks the robustness and precision of high-end equipment. The limitations of this custom-built Pen Plotter, including mechanical and software constraints, are significant factors that could affect the quality of the user tests.

The software controlling the Pen Plotter is based on a free version of GRBL, GRBL is still under development and has not reached the level of optimization required for seamless operation.[30] [32] Issues such as occasional glitches, crashes, and limited system responsiveness were observed in previous interactions with the Pen Plotter before the study. This impacts the overall reliability of the system. By predicting and preventing known and possible errors, the system software will hope to be stable for testing. The training of models used in the user study requires sufficient GPU power. The training device will be trained on the locally stored dataset. Long training times are expected to achieve the desired accuracy and reliability.

The study conducted will be with a sample group, which may not be representative enough to generalize the findings. This limitation necessitates caution when interpreting the results. Additionally, the study may not fully capture the versatility of the robotic system. As previously mentioned, art evaluation is inherently subjective. While scales and scores provide valuable insights, user experience and perception add additional value for a deeper understanding of the experiences with the co-creative system. The questionnaires developed for the study will incorporate both as well as possible.

2 Literature Context

To understand the co-creative system, it is essential first to clarify what a Pen Plotter is and what it can do. This chapter provides historical context on Pen Plotters and drawing machines and then examines the mathematicians, engineers, and artists using these tools. Given that the Pen Plotter is a machine guided by human input, the interest lies in the humans who have influenced the development. Additionally, this chapter addresses terminology related to the creative process, authorship, and computer art and explores co-creation systems that have impacted the evolution of Pen Plotters.

2.1 History of computer art and the influential artists

What is a drawing machine? A drawing machine or Pen Plotter is an output device that reproduces graphics by transferring ink or paint onto a drawing surface. The first device considered a Pen Plotter is the Calcomp 565 drum plotter[1], a drum plotter introduced in 1959 that uses a rotating drum and a horizontally moving pen.

Before the public had access to Pen Plotters, Desmond Paul Henry, a lecturer in philosophy teaching in Manchester and a self-taught artist, used analog bombsite computers to develop his drawing machines. The intended use of the bombsite computers was to calculate the trajectory of bombs released by bombers in World War II; the first of these machines can be seen in figure **??**. This did not stop his creative mind from manipulating these machines to do something drastically different.[13]

[1] *Calcomp 565 Digital Incremental Plotters*, accessed May 30, 2024, `https://ub.fnwi.uva.nl/computermuseum/calcomp565.html`

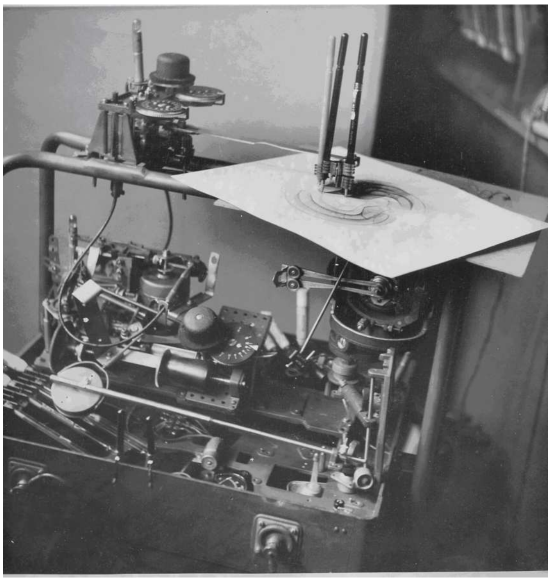


Figure 2.1: The first of Desmond Paul Henry's drawing machines. Source: Desmond Paul Henry, *First Drawing Machine* (accessed June 6, 2024, `https://desmondhenry.com/media/1015/bombsight-computer-02.jpg`).

Figure 2.2: A drawing from Desmond Paul Henry's first drawing machine. Source: Desmond Paul Henry, *Drawings Created by Desmond Paul Henry's First Drawing Machine* (accessed June 6, 2024, `https://desmondhenry.com/gallery/`).

After working with the machine for nine years, he decided to repurpose it into a drawing machine in 1961, just as the world of computer art started gaining attraction. Henry continues to develop three drawing machines over the next ten years, gradually improving the size and accuracy of the machine. Comparing his machines to other available machines shows how different they were, as all other drawing machines on the market needed to be programmed. To do so, the person using them first needed to make up the graphics desired and then program a computer to tell the machine which lines to draw. Henry's take on this was more intuitive; his machines could not store information or be programmed; they were turned on and started drawing; during the process, Henry would interact with the machine by moving the pen manually or holding the paper to change its position, allowing an interactive creation process. [26] [13]

After the development of drum plotters, flatbed plotters such as the HP 9125A were first introduced in 1968. The HP 9125A had a drawing surface of 25.4 cm × 38.1 cm and used an electrostatic hold-down technology to keep the paper in place[2]. The flatbed plotter held the paper flat instead of in a drum shape, allowing for more precise and versatile machine handling. These flatbed plotters set the first standard in drawing machines. Both of these are XY-Plotters; in the drum plotter, the drum would spin back and forth (Y-Axis) and then the pen would move horizontally (X-Axis). The flatbed plotter holds the paper in position and then moves the pen freely along the x and y directions. The plotter developed for this system falls into the category of Computerized Numerical Control (CNC) plotters, using the benefits of a historic flatbed plotter but with a modern control unit.

The field of Pen Plotters and drawing Robots began gaining attention in the early 1960s. Various versions such as Flatbed-Plotters, XY-Plotters, and multiple adaptations have been used to create mesmerizing art over the years. Known as 'Computer Art', pioneers such as Manfred Mohr, Vera Molnar, Georg Nees, and A. Michael Noll introduced the field to the public. The second public exhibition in 1965 in the Howard Wise Gallery in New York City featured works from A. Michael Noll. Some claim this to be the first exhibition of computer art in the world, but earlier that year, the German Hochschule of Stuttgart showed works by Frieder Nake, Georg Ness, and Max Bense. This exhibition showed Pen Plotter drawings and other drawings created by computers. Either way, the year 1965 marks the beginning of the Computer Art movement. [11]

Harold Cohen, with the development of A.A.R.O.N., his drawing robot, and later Casey Reas [31], the co-developer of 'Processing', a Java and Python-based tool for artists, expanded the field and generated multiple waves of attention through the following decades. Unlike the early pioneers, Casey Reas comes from a programming background and is not a mathematician. In the 1960s, computer art was done without graphics software; in the 1970s and 1980s, technologies advanced and allowed artists to use software to manipulate shapes and geometric forms. These advancements allowed machines to take on a more active role in the creative process, generating complex patterns and artworks with minimal human input. However, the artist's intuition and initial programming still played a crucial role in the machine's output. Since then, generative art, where artworks are created through autonomous systems such as algorithms, has become a significant area through software such as *Processing*.

[2]HP Computer Museum, *HP 9125A Plotter*, accessed June 30, 2024, https://hpmuseum.net/display_item.php?hw=82

Artists like Joshua Davis and Marius Watz use code to generate patterns and forms, emphasizing the artist's role as a creator of systems rather than just images. These artistic results lay in between the world of digital and physical representations. Examples are digital-generated geometric, mapped onto walls with projectors and copied with painter tape, seen in Marius Watz *Wall Exploder B, 2011*[3], or as seen in Joushua Davis *Anderson Ranch Prints, 2015*[4], algorithmic pattern printed, plotted, cut with a laser cutter or printed on shirts. These art projects use all sorts of digital and physical mediums to present them. Developing software tools like *Processing* by Casey Reas and Ben Fry revolutionized creative processes for artists working with any medium. These tools provide a framework for creating complex visual works through programming, allowing artists to focus on the conceptual aspects of their work while the software handles the technical execution.

The Internet allowed interactive works to be shared online, and the 1990s were revolutionary for computer art and all digital media within it. The last decade saw many new and diverse ways to display art, from A.R. and V.R. to A.I. Computer art is opening a whole new spectrum. Nowadays, computer art is often confused with A.I. or generative art. New media uses the old terminology, leading to confusion within the field.

Using past datasets in new art, in the sense of learning from the art from the 1960s and its creation process, including new media, led to a rise in digital art in the early 2020s. With the rise of blockchain technologies, so-called NFTs (Non-fungible tokens), which give verified ownership over digital assets, allow the sale, buying, and collection of these assets. On the one hand, all of this is computer-generated art, but it needs to be clear that the original *"Computer Art"* means physical art created with the help of a computer. The term digital art means digital art pieces generated either entirely or with the help of a computer.

2.1.1 Creative Process and Authorship

The question of authorship in machine-assisted creation is complex. When a drawing machine creates an artwork, who is the actual author? This question touches on

[3]Marius Watz, *Wall Exploder B*, 2011, accessed July 30, 2024, `https://mariuswatz.com/2011/07/21/wall-exploder-b/`

[4]Joshua Davis, *Anderson Ranch Print 2015*, accessed July 30, 2024, `https://joshuadavis.com/Anderson-Ranch-Print-2015`

creative ownership in the digital age, which will become more critical as artificial intelligence and machine learning advance. As machines now can produce original works, the question of authorship covers more than just who owns a produced work: is it the developer of the artificial intelligence, the company standing behind it, the user entering the prompt, the person coming up with the prompt or is it the machine itself? This topic also included the rights to the piece and who should have the right to share it, manipulate it, sell it, or even use it to train another machine-learning model on top of generated images. This paper will only touch the surface of this ethical debate by focusing on the co-creation with a Pen Plotter and the creation process; authorship is secondary. Nevertheless, questions like these are important to discuss. The debate around authorship is not new in the art world, and new developments will continue to make it more complex.

More important for this thesis is the creative process, which refers to the sequence of thoughts and actions that lead to the generation of ideas, or in this case, artworks. As humans, we are one of the only species with a brain capable of new ideas and creative thoughts, involving several stages, including preparation, incubation, illumination, and verification.[33] Each stage plays a critical role in transforming abstract ideas into concrete outcomes. The process is natural, and it's how our brains function. The initial stage is preparation, gathering information, material, and inspiration for a problem solution or task. Next is the incubation phase, which takes a step back from the problem and allows more general ideas to develop without directly focusing on the task. Often leading to insights that haven't been visible before. The illumination phase then summarises the results, often called the "aha" moment, when the idea emerges clearly. It's when all the information gathered sorts itself, and a concept becomes visible. Lastly, in the verification phase, we refine, elaborate, test, and adjust the concept to a final idea. [33] This concept happens so fast that we don't even notice it; when drawing with a pen, our brain goes through these phases before each stroke, before each turn in a line, before we lift the pen of the paper. It is an iterative process that is not always linear and clear. Many factors influence each step of the thinking, and adding another partner in creation increases variables and factors. [24]

Co-creation is the collaboration between humans and machines; machine learning algorithms and artificial intelligence can assist in creating. Ethically, this leads to more and more questions: Do we need to be assisted with such a complex functioning brain? Does the support or the machine always help, or could it be confusing? These questions won't be answered in this paper but are kept in mind during the development.

2.2 Related Works

Now, commonly known as a drawing machine, Pen Plotters are advertised as machines that can draw vector graphics on paper or write in a handwritten style. "A printer does the same thing, just faster and in colors", "more expensive than a printer", and "complicated and nonuser friendly"[5], and others are just some of the comments which can be found on the web. The niche of makers and creators that still enjoy using these devices do it by heart, most of the Pen Plotters are custom-built from other machinery or old parts. Plenty of how-to examples are spread over the web, allowing you to build your own with little to no technical understanding. In the following chapter, projects and works will be presented. Some of these are very similar to the co-creative system described in this paper and others have similar elements but were developed with a different goal in mind. The Pen Plotter is a capable yet straightforward machine that allows interactive creation between a human and the robotic world.

The study *It Takes Two: Using Co-creation to Facilitate Child-Robot Co-regulation* explores how co-creation can enhance child-robot interaction. This approach aims to improve children's sense of control and acceptance of a robot by making interactions more personalized and meaningful. The research found that co-creation activities facilitated collaboration and positively impacted children's perception of the robot.[23] Even though my test subjects aren't children, the focus on the co-creation process applies to my system.

Human and Machine Symbiosis - An Experiment of Human and Robot Co-creation of Calligraphy-Style Drawing describes a project named "Robot Painter" which explores human-robot co-creation in calligraphy. The system uses convolutional neural networks to convert raster images into calligraphy-style images. The images are then processed through software to generate a 3D toolpath, similar to G-code, for a KUKA

[5] Maker Forums, "Discussion on CNC Technologies," 2023, accessed September 1, 2024, `https://forum.makerforums.info/`

robotic arm, which has a brush attached instead of a pen. This system co-creates before the drawing process by allowing the user to influence the image generation. The robotic arm then draws the image by itself.[28]

The chapter *AI Creativity and the Human-AI Co-creation Model* from the book *Human-Computer Interaction: Theory, Methods and Tools*, explores the development of AI-driven creative processes and the interaction with human creativity. Focus on creating models that enable effective co-creation between humans and AI. They discuss various frameworks and tools that facilitate this collaboration, aiming to enhance the creative output through the synergy of human intuition and AI capabilities. The study highlights the potential for AI to support and expand human creative processes rather than replace them, emphasizing the collaborative potential of AI in creative fields.[39]

Since Pen Plotter doesn't give the same freedom of drawing simultaneously as a virtual canvas, turn-based systems are more valuable for the rest of the paper. A simple take of this is DuetDraw[27], a turn-based system in which a user draws on a virtual system's and the system's continuous sketch-RNN's Sketch-RNN's capabilities, recommending which space to fill or offering a style transformation is just a few features.[22] Fusing modern AI into existing drawing models in a simple interface gives a feeling of genuine cooperation. The user and the system draw their parts, resulting in a piece consisting of lines and shapes similar to what could be created with a Pen Plotter.

A recent study from 2020 tries to understand human-human cooperative drawing with an online drawing tool. Humans connect online and take turns sketching lines in a scene; each turn has a set amount of strokes, and the participants vote on the version that should be used in the next round. The voting system proved to give results with higher creativity. Alongside the drawing, there is no other communication, and the system is anonymously.[29] This iterative process of drawing in turns and then voting to continue adding more elements to the creation is comparable to a conversation. The participants are given creative input, but the group then decides what to do next, the same way we direct conversion from topic to topic. The final results of this study show vibrant images in which each participant contributed some creative work.

These works inspired my co-creative drawing machine. But it was not until I visited a seminar, held by Frieder Nake in 2020, that I learned about the general concept of computer art and its development since the early 60s. By showing and explaining artworks in detail, hearing this from someone who was there when all this happened and someone who had met fellow mathematicians and artists from the time, it felt real. Introducing numerous names; many were not artists but mathematicians or engineers with a high sense of aesthetics. The history and the, now ancient, technology used to make these pieces inspired me. One of the artists in computer art is Sougwen Chung[6]. The Canadian artist experiments with many art styles, but her D.O.U.G. (Drawing Operations Unit: Generation) inspired everything I did with the Pen Plotter. Sougwen Chung started her project in 2015 and has completed two follow-up projects. These art projects focus on the aesthetic aspect of robotic arms, drawing in collaboration with her. Drawing Operations Unit: Generation (D.O.U.G.) 1, 2, and 3 have influenced the development of the idea of using the Pen Plotter to interact with humans. Chung interacts with her projects, but here again, it's always her and the robot, never an outstanding user, someone without knowledge about the system. When she hosts live exhibitions it's her, one on one with her system.

Taking inspiration from the works above, a cooperative, co-creation system with a Pen Plotter has been tested before, but there is little insight into the process of creation. Result-focused studies with aesthetics in mind are very valuable, but they focus on a different aspect than my study. However, to understand how we humans create and how a robot could assist us, the focus should be on researching the creative process during the creation itself.

[6]Sougwen Chung, *D.O.U.G: A System for Exploring Art with AI*, accessed August 5, 2024, `https://sougwen.com/works/doug`

3 Cooperation

3.1 Physical and digital drawing compared

Understanding the Pen Plotter and its history raises important questions: Why use it in this context instead of creating a digital co-creation system with a digital drawing surface? What are the potential advantages of an analog drawing setup?

Digital art can be defined as artwork created, stored, and manipulated using digital technology. It involves using computational processes and algorithms, which artists can control or run autonomously to generate visuals. The computer assists in the creation and engages with symbols, data manipulation, and human-computer interaction to form new aesthetic experiences. [25]

Physical art is the traditional form of creation using materials like paper, pens, paint, and other tangible objects. Drawing is the oldest art form known to humans, from cave paintings to papyrus, canvas, fibre and ceramics. The oldest cave paintings in the world can be found in the Chauvet Cave in France. They are estimated to be 30,000 to 32,000 years old[5]. In drawing, physical art involves direct interaction between the artist and the materials. Unlike digital art, physical art is less forgiving; once a line is drawn, it is permanent. While a pencil stroke can be erased, traces of it remain. Similarly, a canvas can be painted over, but some forms of drawing are final once applied.

Each medium offers benefits. Digital art provides flexibility and ease of modification, while physical art offers a tactile and permanent connection to the creative process. Combining the Pen Plotter, which lies in between these mediums, with traditional art materials creates a bridge between these two worlds, offering the precision and repeatability of digital tools with the tangible, permanent nature of physical art. Both allow one to express creativity and produce thoughts, emotions, or a message on a surface. Art is a matter of perception. Therefore, neither is better or worse; both have their use cases, and personal preference mainly decides which one to use. Often, the choice is made to fit a requirement. Logos for companies often need to be digitized, and art in galleries is usually physical.

Digital art is correctable; layers can be moved or removed, brushstrokes can be adjusted, and colors can be changed. Adjusting the digital image is possible when utilizing a Pen Plotter, but the physical outcome is not. Generating an art piece and then letting the plotter draw it is different. Once the Pen Plotter draws on the paper, lines cannot be removed, colors can't be changed, and layers can't be moved. Even though it's a digital art piece that was created, the two different art worlds overlap once it is brought into the physical world. Even when letting the Pen Plotter draw the same digital piece again, subtle variations will give the physical piece authenticity. As mentioned, it's personal preference which art form is used; some people don't enjoy the digital creation process as much. Possibly, it is the age of the artist since the drawing tablets were first introduced by *Wacom* in 1984 [1]. Physical drawing methods and techniques developed over centuries are diverse and widely spread through culture. And due to technical advancements, they are being used less and less. Choosing a combination of the two allows the co-creative system to utilize the modern technology of tracking systems and stroke detection with the materials and benefits of the haptic art world. This is why the Pen Plotter was chosen for this system. [40]

3.2 Science of Physical Drawing

Is there a science behind drawing? How can we gain insight into the thought process of a human drawing? Could this lead to insights that could improve the creative process in a co-creative system between a human and a robot? In early empirical studies from the 1970s and 1980s, video was used to track hand and pencil movement. This research output was a systematic list of preferred direction and stroke orders. These mechanical features were supposed to give insight into artists' cognitive thought processes in drawing. The authors' results lead us to believe that drawings consist of layers, with drawn strokes on top of which geometric primitives sit. Additionally, artists might not consciously create these structures; a more complex analytic method would be needed to understand this.[34] By analyzing the movement of the artist's eyes, it can

[1] Wacom, *About Wacom*, 2024, accessed August 3, 2024, `https://www.wacom.com/en-us/about-wacom`

be estimated where the attention lies. When drawing subjects, the gaze shifts between the subject and the canvas; therefore, the attention switches between the subject and recently drawn lines, making it harder to be certain which processes happen at which time.[37]

3.3 Robotic Drawing Systems

To have a system where humans and robots co-create, there needs to be a robotic system; the most famous one is the *AARON* robot from Harold Cohen. Cohen said *AARON* is an extension of his artistic style. Cohen spent decades working on *AARON* by asking himself, "What makes an image?" or "What are the minimum conditions under which a set of marks functions as an image?". From the 1960s to his death in 2016, Cohen used *AARON* to create drawings, paintings, compositions, and abstract works. Harold Cohen did not believe in the concept of Machine Learning; he believed that artists needed to be in control of developing the system. [7] Another system strongly influenced by its creator is a portraiture robot called *Paul*. Patrick Tresset created *Paul*to be able to draw human portraits from different angles and perspectives. Using a webcam for image capturing and some image processing to define contours and facial features, the robot sketches portraits on paper. Like a Pen Plotter, the robotic arm of "Paul" sketches the abstract version of the captured image. The human role in co-creation is to be, enjoy, watch, and learn. The user has no manual input, allowing for a unique interaction.[35] Another work by Tresset, "Human Study 3 Peter", involves two robotic arms: one draws with an erasable marker on plexiglass, and one has a cloth attached to it to erase the marker's drawing. Taking an element commonly used in digital drawings, erasing symbolizes a conflict between the two arms. [2]

Moving away from robotic drawing systems, "The Painting Fool" system uses software only to simulate the behavior of artists. Choosing its materials, painting style, and stroke style, the software draws images on a digital canvas. In addition to the piece, the system outputs a description by generating text and an argumentation for the work, giving it meaning. The goal is to create an artistic system that others take seriously; input such as emotions is considered when creating pieces.[8]

[2] Patrick Tresset, *Human Study 3: Peter*, 2024, accessed August 3, 2024, `https://patricktresset.com/new/project/human-study-3-peter/`

The advancement of machine learning, deep learning, and neural networks has significantly impacted digital art creation. Generative Adversarial Networks (GANs) [14] introduced the concept of 'AI Art' and sparked a wave of innovation in AI art systems starting in 2014. Today, we witness the evolution of generative artificial intelligence with technologies like GPT's(Generative Pre-trained Transformer), Stable Diffusion models, DALL-E, Runway ML, and many more.[3] These advancements demonstrate that the field is progressing rapidly even a decade later. These systems differ from the original drawing robots; they are data-driven software-only packages. Creating digital art utilizing convolutional neural networks (CNNs), the results are pixel-based images. They can imitate artistic styles and stroke styles from specific artists, but in the end, they can only use the data they have been trained on to learn from. Unlike the previous stroke-based models, each stroke is drawn independently and can be changed independently. Some modern systems could be seen as cooperative since a user needs to interact somehow with the software by entering a prompt or providing a software image or video. Nevertheless, the user does not influence the creation process. Therefore, whether the user holds any authorship to the outputs is questionable. Also, multiple users could use the same input image and generate similar results with the same software, leaving the authorship question open.[2]

3.4 Co-creative Systems

Co-creative systems come in many forms, depending on how co-creation is defined. A co-creative system refers to a collaborative tool where humans and machines work together in real time. Blending human creativity with the machine's computational and mechanical abilities, these systems help generate or refine creative content by allowing humans to provide inputs. While machines respond through actions like predicting frames or refining designs[19]. They can range from simple tasks like enhancing geometric shapes to refining existing drawings and even offering real-time support for artists. The research literature on sketch-based interaction has tools designed to assist artists as they draw [1]. Cooperation with a machine allows for generating new images by predicting subsequent animation frames or estimating colors for various parts of an image with predefined values. These systems support the artist's thought process in real time through overlays, vocal prompts, or sketch clean-up features.

One system that uses the overlay feature seen in many digital drawing devices is *Shadow Drawing*. It uses an underlying 'shadow' to support the drawing process by giving an idea of proportions and scale while allowing the user to draw whatever they want on top. The system detects what the user is trying to draw and suggests how to continue. The simple yet creative system improves general sketching by updating the 'shadow' as the user draws in real time, allowing the user to follow or ignore the guidance shadow during the process. The final piece consists only of lines drawn by the user [21].

The Drawing Apprentice, published in 2016, uses another software approach by allowing a user to draw on a virtual drawing surface, and the system will add complementary elements to the drawing and communicate via an avatar and a text chat. The AI allows turn-based and asynchronous drawing on the virtual canvas. Inspiring the first drafts of my cooperative system, the Drawing Apprentice has a real-time tracking system detecting shapes and objects. Different modes such as mimic, add to the drawing, or trace gave me ideas for my first system drafts [10]. When comparing the "Shadow Drawing" system with the "Drawing Apprentice," the key difference lies in the level of support they provide. The Shadow Drawing system offers guidance without altering the drawing, thus having a subtler influence on the user's work. In contrast, the Drawing Apprentice provides more substantial support, significantly impacting the piece in terms of content, style, and color, depending on the mode selected. While this enhanced support can lead to improved results, it may also affect the user's experience, either enhancing their satisfaction or causing frustration based on personal preferences.

Leaving the virtual canvas behind and returning to traditional media, the publication *Dialog on a Canvas with a Machine* brings the concept of the Drawing Apprentice into the physical world. In this system, two artists alternate drawing on a canvas. When one artist finishes their turn, a camera captures the current state of the canvas and sends it to the software. A projector then displays suggestions for the following strokes directly onto the canvas. The canvas lies on the floor, and the camera and projector are mounted to the ceiling above the canvas. Each artist can use the suggestion or ignore it when drawing their stroke. The suggestions are generated by the Sketch-RNN model trained on the QuickDraw Dataset and additional works by the artists themselves. The system's suggestions are not definitive but serve as creative support to guide the artist's next steps. Taking it away from the digital canvas reintroduces stroke-based drawing, showing the importance of each line and proving that each line is placed with thought in mind. For each line drawn, the artist goes through the creative process previously explained, with additional input from the support system and its suggestions[4].

The QuickDraw dataset, used by both *Dialog on a Canvas with a Machine* and the co-creative system discussed in this paper, includes sketches from detailed drawings to minimal strokes. The dataset is divided into 345 categories, such as bucket, camel, donut, elbow, drill, knife, ladder, passport, police car and owl, to name a few. These do not cover the full spectrum of potential drawings our brain could develop. Nevertheless, its extensive collection of over 50 million samples offers significant diversity within each category, making it a valuable dataset for creative support systems.

Few projects push co-creation as far as drawing on a physical canvas or paper. A project from 2017, detailed in the paper "Design and Evaluation of a Drawing Robot for Art Therapy" by Martin D. Cooney and Maria L. R. Menezes, aimed to design a drawing robot to assist users in art therapy. This robot was designed to interpret and respond to the user's emotional state, learning from their drawings. Analyzing the artistic style to contribute to the painting process by integrating emotional feedback with artistic creation, the robot offered a unique and interactive approach to art therapy, enhancing both the creative and therapeutic experience [9]. Compared to digital tools like the "Shadow Drawing" system and the "Drawing Apprentice," which offer varying levels of support and guidance, this robotic system extends co-creation into the physical world and combines creative support with emotional interaction and artistic collaboration.

Research on artistic collaboration often emphasizes systems and tools developed by artists themselves. These systems are typically designed to the individual needs and interests of the creators rather than focusing on error elimination and software improvement for bug reduction. For instance, Sougwen Chung's D.O.U.G system was developed over many years and refined through iterative testing and personal adjustment, always to her liking without influence from other users [3]. Similarly, the Dialog on a Canvas with a Machine, designed by artists for personal use, was not primarily intended to enhance the creative process during production. Instead, it was developed to showcase it in exhibitions.

[3] Sougwen Chung, *D.O.U.G: A System for Exploring Art with AI*, accessed August 5, 2024, `https://sougwen.com/works/doug`

These systems are crucial because they produce artworks associated with their creators, simplifying the authorship question. They don't have low levels of creative support; the focus lies on the art, not the co-creative system. In contrast, digital counterparts often introduce complexities regarding authorship. When AI, deep learning, or others are involved in the creative process, balancing the contribution between humans and machines can be challenging. The resulting artworks may raise questions about the extent of the artist's input versus the system's influence, making the allocation of authorship more complex.

3.5 The Significance of Co-Creation

Exploring physical and digital drawing shows how the choice of tools affects the creative process, the question of authorship, and the final artwork. Using a Pen Plotter combines traditional techniques with modern elements, merging the precision of digital tools with the haptic nature of physical art. Robotic drawing systems like *AARON* and *Paul* demonstrate artistic possibilities and offer new ways for artists to collaborate. These systems extend the artist's vision and provide new ways of co-creation. Co-creative systems, including 'Dialog on a Canvas with a Machine', reveal the complex creation process between human creativity and machine assistance. These systems challenge traditional ideas about authorship and originality, raising questions about the artist's role: Who ultimately holds authorship when both human and machine contribute? How does the degree of machine involvement affect the perception of the final artwork? And, can a machine be considered a true co-creator or merely a tool?

In summary, using a Pen Plotter provides access to both worlds. This approach explores new creative possibilities while staying true to the artist's vision. By learning from the other systems, my co-creative system should focus on the creation process, assisting the user as much as necessary but giving users the space and freedom to make their own choices.

4 Methodology

4.1 Design of the Co-creative System

In a co-creative system, both humans and robots interact as creative work partners in the process. Drawing inspiration from other co-creative environments, the methodology and design process behind the development cannot be neglected. The following themes are the focus when developing the co-creative system.

Design with Purpose: The purpose of this system is not to be exhibited or shown in a public space; therefore, it does not need to withstand the level of use typical of public installations. Additionally, there will not be multiple users testing it simultaneously, which simplifies error management for multiple pen strokes and tracking systems.[16] At the same time, the system should convey seriousness through a simple yet effective design, offering the user the best possible haptic experience.

Another crucial element is the safety of both the user and the system. A stable testing environment, including hardware and software, cannot be ensured if the system is unreliable. Common errors can be eliminated through iterative testing, and less common errors can be addressed afterwards. The Pen Plotters setup includes only weak stepper motors with insufficient rotational force to cause severe injuries and a 12V power source maxing out at 200mA. Ensuring that all components are securely held in place and that no open wiring is accessible to the user is a priority in the testing environment.[18]

By understanding how the creative thought process functions, the system can be built to support the user rather than complicate it with a complex setup filled with distractions. Lessons learned from prior research in turn-based co-creative systems apply to the action-based turn-taking system. When it is the user's turn, the robot should not move. This means the robot should not distract the user by movement, sounds, or flashing lights.[38]

Balancing design with the research goals is crucial. To achieve meaningful research, the emphasis is on the study rather than the system's design. The focus is on understanding how the system influences the creative process and who has ownership of the piece after the creation process. Placing importance on this over a polished design is necessary. This does not mean that design is not essential; instead, incorporating design considerations into the development process using the points mentioned above will ensure that the system supports research with meaningful results.

4.1.1 The Pen Plotter

The Pen Plotter is custom-built specifically for this project. Its base is constructed from aluminium rods arranged in an XY configuration, reminding of the old XY plotters from the late 1960s. A cart is mounted on the x-axis and moves horizontally to adjust the x-coordinate. The y-axis, connected to this cart, moves left and right. The y-coordinate is adjusted by moving the pen mount along the y-axis. Steel-bearing balls allow for smooth movement between the cart and the rods. NEMA stepper motors and a belt system control the axis movement. Each axis has its own NEMA stepper motor and GT2 belt system, allowing individual control of the axis. A 4.8g micro-servo, enclosed in a 3D-printed case, functions as the Z-axis. It has a spring, a pen mounting system, and additional 3D-printed components, allowing the servo to lift and lower the pen. The pen sits in a green printed pen mount that fits the pen's diameter. All this is done to keep the parts lightweight and allow the use of the small servo. The Plotter sits on a piece of MDF. This design prevents the plotter from sliding or moving when placed on a table. The final version of the Pen Plotter setup can be seen in figure4.1. A close up of the Pen Plotter can be seen in figure 4.2

Figure 4.1: The Pen Plotter set up for the study

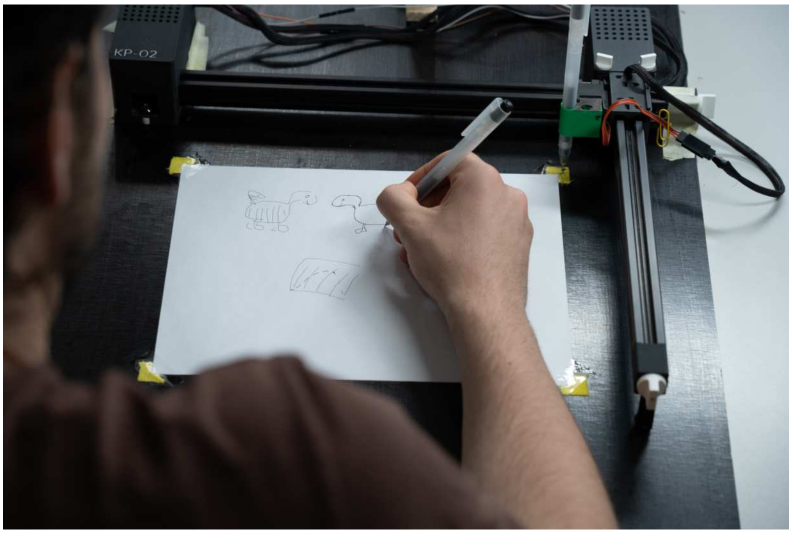


Figure 4.2: The Pen Plotter and a participant drawing during the study

The system's core is an Arduino UNO microcontroller housed within the main compartment on the left side of the plotter. This microcontroller provides both power and intelligence to the Pen Plotter. Mounted on top of the Arduino is a CNC shield that controls the two NEMA stepper motors, which drive the belt system. Most of the wiring is housed in a case on the left side of the plotter along with the Arduino, ensuring a stable and flat-standing robot. Tiny legs are concealed on the underside of each support rod to adjust its height. By turning these legs, the height of the support rods can be increased or decreased. The cart connecting the two axes is fixed at the end of the y-axis and moves freely along the x-axis. The cart has a removable pin, allowing the plotter to fold along the y-axis for easy transport without the need to remove the belts or cables. Aside from the custom parts, the only additional hardware includes some M4 and M3 screws and washers integrated into the 3D-printed parts.

4.1.2 Concept and Framework

The software running on the Arduino is a custom version of the open-source GRBL, specifically GRBL version 0.9. GRBL is a widely used software for homemade CNC and laser engraving machines. It enables control of the NEMA motors connected to the CNC shield and allows the Arduino to interpret two-dimensional G-code. An example of such a G-code is *G01 X100 Y100 F10000*. Here, G01 indicates a linear interpolation command. X100 instructs the machine to move to the x-coordinate 100, while Y100 directs it to the y-coordinate 100. F10000 specifies the feed rate, telling the NEMA motors to spin at 10000 mm per minute. Standard G-Code is three-dimensional and includes a z-axis command.

Since this system uses a servo to control the z-axis, the M3 command to control the servo via the CNC shield. This allows the servo to move independently of the X and Y axes. The M3 command, typically used for the milling spindle, is repurposed here to control the servo. An example command for servo movement would be M3 S90. In this context, M3 sets the milling spindle, which, in this case, is the servo. S90 would usually denote spindle speed, but here, it sends a Pulse Width Modulation (PWM) signal to the servo, rotating it by 90 degrees. Valid commands for the servo range from S0 to S100, adjusting the servo from its 0-degree position up to 100 degrees. Only the commands "Pen up" and "Pen down" are relevant in the current system. GRBL is written in C and C++; all other software components have been developed specifically for this project and are written in Python.

4.2 Development Process

This setup was designed to minimizes interference with the user's creative process, allowing free thought without restricting sight. The design objective is to make the user feel like they are drawing alongside a partner, fully immersed in the process.

Initial tests revealed that drawing simultaneously on A4-sized paper with the Pen Plotter was challenging. Some people lean over the paper; others draw from the side, and some use either their left or right hand. Consequently, a turn-based drawing process was implemented. In simultaneous drawing, the Pen Plotter's arm obstructed parts of the paper, affecting the user's visibility. Additionally, the plotter cannot be touched during drawing, which could cause misalignment and require recalibration of the setup. Tests with a plotter using a long belt system controlled by both motors simultaneously gave similar results; even with larger-scale Pen Plotters, the arms obstruct vision and interfere with the user. Simultaneous drawing would be possible only if the plotter and paper are even larger or if the plotter's pen and arm can detect the user's hand and stop when it is too close to the moving axis.

The initial concept involved the following setup: The Pen Plotter and the user are positioned at a table. The user can draw on the paper without restrictions, while the plotter remains idle until the user finishes. After both have completed their drawing cycle, the user can add more or leave the drawing as it is. A camera mounted above the paper on a tripod, with two bright LED lights for even lighting, tracks the user's drawing. The plotter is centred beneath the camera, and the paper is fixed to the table.

The environment for the user study is as crucial as the system itself. By minimizing distractions, the user can focus on drawing rather than on external factors. The Pen Plotter needed to be adjusted, and the Arduino microcontroller software had to be modified. Initially, the Pen Plotter was controlled by sending commands simultaneously; the Arduino buffer would fill up, and the system would wait for the Arduino to process them sequentially. For an interactive system, this approach was inadequate due to multiple threats running in the background to detect the paper contours and the drawing.

The current system utilizes a 720p camera with a resolution of 1280×720 pixels for tracking the drawing surface. Due to the processing delay caused by the camera's lower resolution, real-time image processing has experienced a noticeable delay, especially during detailed or fast-paced drawings. While a higher resolution camera (e.g., 1080p or 4K) might mitigate some of this delay, it does increase processing time if not paired with optimized algorithms such as GPU acceleration. Although the Pen

Plotter could handle smaller step sizes, which would increase its accuracy, a lower-resolution camera ensured smooth system operation without interruptions. The camera detects shapes drawn by the user and the position of the plotter. This information allows for the translation of coordinates from the camera's coordinate system to the Pen Plotter's coordinate system. The plotter originally features three yellow markers that compute a translation matrix when the system starts. This was later replaced by a separate script, saving the corners of the paper edges and loading them on system start. This was suitable for the study but not for the testing of the system. The paper and the Pen Plotter are fixed to the table to prevent movement during drawing, as is the camera setup. Camera distortion is adjusted before applying the translation matrix. The camera correction matrix is generated using the recommended calibration process for OpenCV. This calibration involves capturing multiple images of a known calibration pattern, in this case, a chessboard, from different angles. The system then detects the corners of the chessboard in each image and uses these detections to compute the camera's parameters. As seen in figure 4.3, the system corrects lens distortions by applying these parameters, improving image accuracy and aligning the plotter's movements. This is common in pinhole cameras.[1]

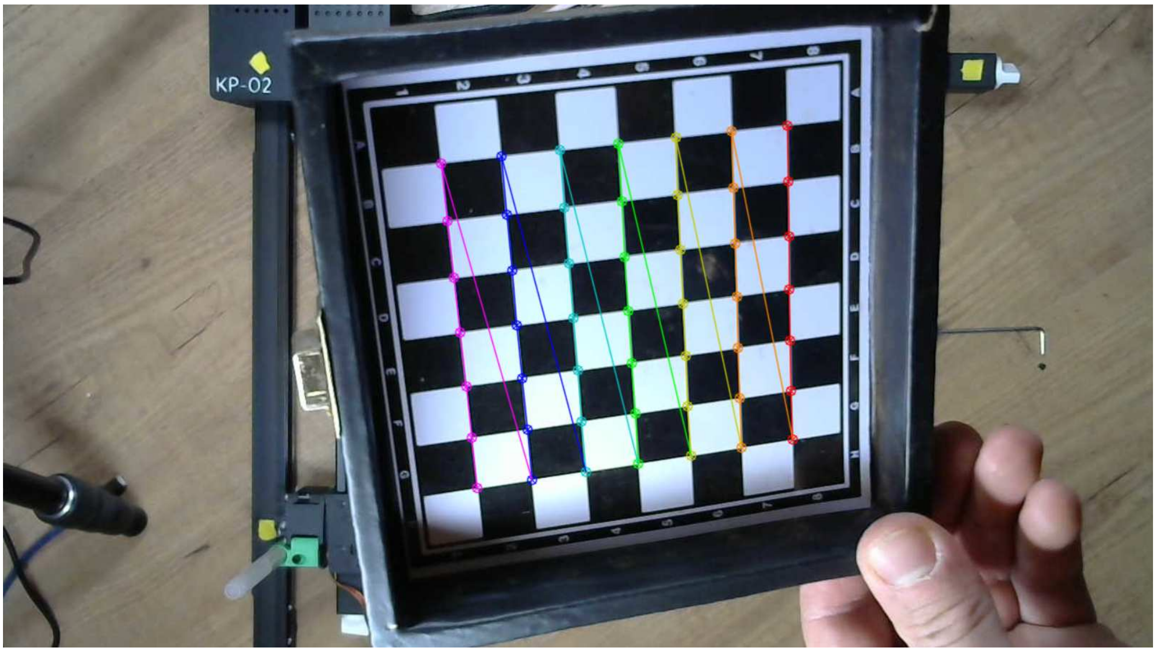


Figure 4.3: The camera correction process using a chessboard

Once a serial connection between the script and the Arduino UNO is established, the

[1] OpenCV, *Camera Calibration and 3D Reconstruction*, 2024, accessed August 12, 2024, `https://docs.opencv.org/4.x/dc/dbb/tutorial_py_calibration.html`

system becomes operational. This connection enables real-time G-code transmission to the Pen Plotter and provides a live feed from the camera on screen.

Upon starting the system, the camera and serial port for the plotter are initialized with the following code:

```
ser = serial.Serial('COM4', 115200)}
cap = cv2.VideoCapture(0, cv2.CAP_DSHOW)
```

The baud rate of *115200* specifies the speed at which the Arduino receives messages, and *COM4* corresponds to the USB port used. When initializing the camera, the index, ranging from 0 to 2, sets which webcam is used. A screenshot is taken, and the script calculates a translation matrix using known real-world distances between the yellow markers on the Pen Plotter. This matrix, loaded from the

```
calibration_data.npz
```

file, accounting for camera distortion using a previously created calibration matrix from the

```
chessboard calibration.py
```

script. During development, the yellow markers were removed, and the real-world dimensions of the drawing surface and plotter were set as parameters in the script. The script loads the four corner points of the paper, which were saved using the

```
paper corner setter.py
```

script.

In addition to computing the translation matrix, the script calculates a scaling factor to adjust the camera's coordinate system. The camera's coordinate system originates at the top-left corner, while the Pen Plotter's coordinate system originates at the top-right corner. To address these differences, the system flips the coordinate system's axes. Once the translations are correctly applied, visual feedback is provided by displaying the border of the drawing surface and connecting the four corner markers with a green line.

The drawable area is used to verify that the paper is within the pen's reach. This area differs from the plotter's coordinate system. The plotter cannot reach the entire surface. The drawable area represents the portion where the pen can draw. Paper detection was initially part of the script. It is not included in the final version of the program, so the paper could be moved until the Pen Plotter begins drawing. For better accuracy during testing, the paper was secured to prevent movement. The best results were achieved by attaching the paper to the board and setting the corner coordinates using a script before starting the program. Adding a margin around the edges helped to accommodate minor calibration errors.

To manage the plotter's commands, the

```
main_for_user_study.py
```

has a queue mechanism, ensuring that G-code commands are handled sequentially. This method prevented command overload and buffer overflow, allowing for smoother operation and reducing the likelihood of an Arduino crash during the drawing process. Serial connection issues were common during development and must be reduced to a minimum for user satisfaction and optimal results. As previously mentioned, threading handled operations simultaneously, enabling the plotter's comands and camera processing to run in real-time. This ensured that the system remained responsive.

Configuration settings, such as plotter calibration data, were stored in JSON files to keep the system consistent. Adjusting parameters outside the script allowed the system to maintain a consistent setup across different sessions. Furthermore, the script handled potential errors during execution through built-in error handling and logging mechanisms, which were crucial during debugging and testing. Additional visualizations, later removed from the script, allowed the optimization of detected shapes and proper translation between camera and plotter coordinates. Plotting the detected shapes in an extra window allowed for adjustments in functions such as

```
def optimize_lines()
```

with visual feedback. This function also simplifies the detected shapes by removing unnecessary points, leading to shorter g-code and faster Pen Plotter drawing. By combining GRBL and adaptive drawing speed, the plotter's speed is based on the complexity of the shapes being drawn. Cornering speed, acceleration, and speed moving while the pen is lifted ensured precise and fast drawing.

The later introduced threshold window allows for real-time adjustments to the detection dynamic threshold value while the system is running, ensuring that lighting and shadows do not influence shape detection. This threshold value determines the sensitivity of the binary conversion when processing grayscale images, affecting which pixel values are considered part of a shape or line. By adjusting this threshold, it is decided how dark or light a pixel needs to be to be included in the detected shapes, making the detection process more flexible. This threshold is crucial in the

```
detect_shapes_on_paper
```

and

```
detect_lines
```

functions, allowing for flexibility in varying lighting conditions. The threshold is adjusted using a trackbar in the OpenCV window, ensuring accurate shape detection for subsequent predictions by the Keras model.

4.2.1 Tools and Technologies

During the development process of the co-creative system, many tools are utilized. The essential tools and technologies will be described in detail. The self-built Pen Plotter, as seen in 4.4, is explained above; this chapter goes into the tools used for the python code controlling the Pen Plotter. The Python libraries used are cv2 for image processing with OpenCV, numpy for numerical operations, tensorflow and tensorflow.datasets for machine learning tasks, math and random for mathematical operations and randomization, os for interacting with the operating system, serial for serial communication, time for handling time-related tasks, threading and queue for multi-threading, json for JSON handling, pynput for keyboard control, requests for

HTTP requests, base64 for encoding, ndjson for NDJSON file handling, svgwrite and svgpathtools for SVG manipulation, datetime for time operations, matplotlib for plotting and visualization, seaborn for statistical data visualization, pandas for data manipulation and analysis, and scipy for advanced mathematical functions.

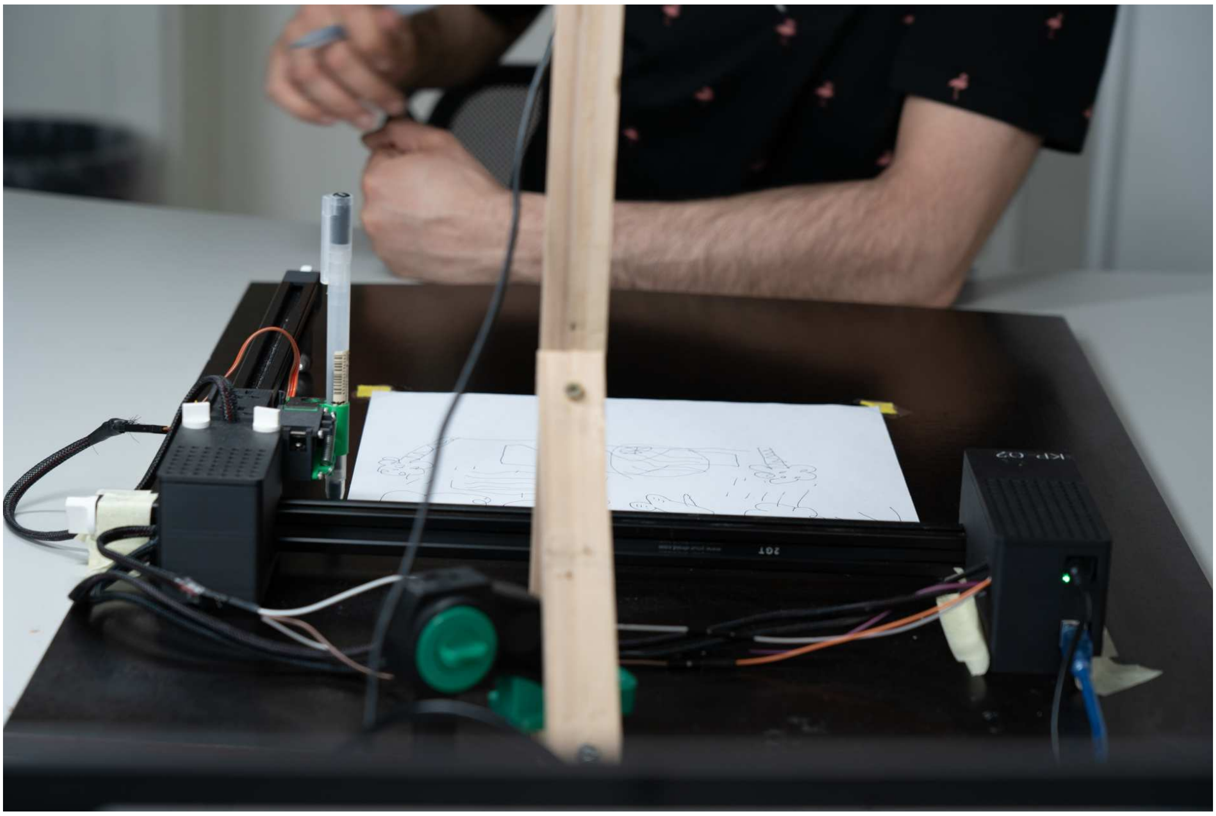


Figure 4.4: The Pen Plotter waiting for the participant to finish the drawing cycle

The *OpenCV* library is used for most computer vision tasks in the software, particularly for detection, calibration, shape and contour detection, color detection, and visualizing the calibration process. The key functions include:

`cv2.cvtColor`, `cv2.inRange`, `cv2.findContours`,
`cv2.getAffineTransform`, `cv2.undistort`.

The *serial* library facilitates communication with the Pen Plotter, primarily by sending G-Code and managing the plotter's responses and state. This ensures that the Pen

Plotter's buffer doesn't overfill and prevents sending erroneous commands. The essential functions are:

`serial.Serial, ser.write, ser.readline.`

NumPy handles most of the mathematical computations, including calculating transformation matrices and processing coordinates. It is also used for distance calculation and applying values such as the scaling factor. The important functions are:

`np.array, np.dot, np.sqrt`

Matplotlib is employed to visualize graphics and plot colorful lines, such as the diagrams in the preview and calibration process. Additionally, *seaborn* and *pandas* are used to generate plots during the evaluation process. *Seaborn*, built on top of *Matplotlib*, utilizes *pandas* for statistical data representation.

Pynput is used to control the system via keyboard input, facilitating testing by allowing individual functions to be executed with key presses. It is also used to start and stop the Pen Plotter's drawing process, with the primary function being:

`keyboard.Listener`

SciPy is employed for advanced mathematical functions, such as generating Voronoi diagrams from detected shapes, which cannot be accomplished with NumPy or Matplotlib alone. The required functions are:

`Voronoi, voronoi_plot_2d`

Although the Voronoi functions have been removed from the current code, they can still be found in earlier versions of the system.

Threading and Queuing are enabled using the *threading* and *queue* libraries. These are used to run the G-code sender in a separate thread, managing the G-Code command queue to prevent buffer overflow, and to run plots in a different thread to maintain a high and stable frame rate for the camera's live feed. The essential functions include:

```
threading.Thread, queue.Queue
```

The *os* library is used for file management during testing and the co-creative process. The primary function is:

```
os.path.exists(path)
```

The *ndjson* library is used to work with the Quick, Draw! dataset, provided as NDJSON files. This library enables parsing and decoding the dataset to generate sketches. The primary usage is:

```
ndjson
```

The *svgpathtools* library allows for the transformation and reordering of SVG file paths to generate more efficient G-code. By scaling the SVG file, the complex transformation of each G-code line is already adjusted. The path order can be optimized to reduce unnecessary movements by the Pen Plotter. Additionally, the *svgwrite* library is used to save the generated vector graphics as SVG files.

TensorFlow is used both for training models and for loading and running the model in the script used during the user study. *TensorFlow* enables easy training of machine learning models, utilizing both CPU and GPU resources. The necessary version of CUDA and cuDNN, provided by *NVIDIA*, is required for GPU training.

The combination of *pandas* and *seaborn* is primarily used for data manipulation and visualization during the evaluation phase. *Pandas* handles the data structures, while *seaborn*, built on top of *Matplotlib*, provides an interface for creating informative and statistical graphics.

The *math* library is employed for mathematical computations such as trigonometry, which is essential in generating L-systems or performing geometric transformations. Functions like:

```
math.cos, math.sin, math.sqrt
```

are used for precise calculations during drawing operations and shape transformations.

The *random* library introduces variability into the system, particularly in selecting random starting positions for drawing shapes or generating random designs. Functions like:

```
random.uniform, random.choice
```

help create more dynamic and less predictable output.

The *base64* library is used for encoding and decoding binary data into a text-based format, which is particularly useful when handling data that needs to be transmitted or stored in a text-friendly manner, such as images or G-code commands.

4.2.2 Steps for refinement

Several helper scripts were created to assist the main script to overcome challenges during the development process. These scripts ensure the system can run in any environment, regardless of lighting conditions or surface type.

When setting up the co-creative system, the script

```
color_picker.py
```

is used to ensure that the correct HSV values detect the yellow dots on the Pen Plotter. By manually adjusting sliders to define the yellow dots' lower and upper HSV values, the later use was defining the color of the paper and lines. Another option is adjusting the lamps' color temperature, which is measured in Kelvin (K). Lower temperatures indicate warm light, while higher temperatures indicate cooler light. Adjusting a knob on the lamp allows for color detection manipulation even after the program starts, enabling fine adjustments without restarting the system. Alongside the threshold adjustment the system will run in any lighting condition.

Initial testing was conducted in a simultaneous drawing environment where the Pen Plotter would draw as soon as shapes were detected on the paper. Baseline tests involved different scripts. In one script, the Pen Plotter saved detected shapes and mimicked them on another part of the paper. In another, the Pen Plotter extended existing shapes by detecting the starting or ending point and continuing the drawing. In a third test, the Pen Plotter was free to draw various geometric shapes with a delay between each drawing cycle. After completing a shape, the plotter would return to its origin and wait five seconds before drawing the next shape.

These baseline tests revealed several issues, such as the Pen Plotter interfering with the user's drawing space and false shape detections from jewellery, watches, and long sleeves, leading to a strict "naked hand" rule. Testing different pens with various ink colors also raised similar issues. Therefore, users are provided with a specific pen made of non-reflective white plastic and black ink. In summary, the drawing environment was sterilized by imposing limitations on the user and the pen, and drawing is done sequentially instead of simultaneously.

The Pen Plotter was later adjusted to go through only one drawing cycle for each user drawing, leading to faster testing during the user study and simplifying shape detection. This also allowed the Pen Plotter to use the same ink color as the user, resulting in an image where the user and Pen Plotter lines merged into one drawing.

Technical adjustments after the baseline tests led to a different camera setup. Initially, a high-resolution camera was used for detection, but it resulted in a low frame rate on the live feed, slowing down the system. It was replaced with a smaller webcam with a resolution of 1080×720 pixels, which proved sufficient for capturing detail in basic drawings.

4.3 Evaluation Methods

A user study is designed and conducted to evaluate the system. The following chapter explains how the underlying research is structured and what the participants expect from the study. To objectively evaluate the outcomes of this user study, the methodology developed by Erin Cherry and Celine Latulipe[6] was deployed. The HCI researchers designed the Creative Support Index, or CSI for short. They based the Creative Support Index (CSI) on NASA's Task Load Index (TLX). The Task Load Index is designed for productivity assessment and follows a simple evaluation method in which six categories are rated on a scale from low to high; the CSI aims to provide a similar index for creative tasks. The six creative factors are Collaboration, Enjoyment, Exploration, Expressiveness, Immersion, and Results Worth Effort[6]. Each factor has two questions, rated on a Likert scale from 1-10. After rating each factor, a second part of the questionnaire begins. In this section, each factor is set against every other factor. The user must decide which of the two factors was more important during the activity, resulting in 15 comparisons.

The CSI was developed to give systems a score representing their level of creative support. However, evaluating the Pen Plotter required additional measures to capture broader insights. The questionnaire was expanded to include four questions in the demographic section to cover participants' previous knowledge and expectations. Further questions were asked after each test run, covering four broad research fields: Dependency on AI in drawing, creative support of the machine, sense of authorship, and satisfaction. Finally, at the end of the study, participants answered further questions to gather more insights.

The CSI score is calculated by first summing the agreement statements for each factor to get a factor subtotal. Each factor subtotal is then multiplied by its factor comparison count (i.e., the number of times it was chosen in the factor comparisons). Finally, these are summed and divided by three to produce an index score out of 100. A higher score indicates better support during the creative process. Calculating a score for each test run and a total score for the Pen Plotter system allows comparison to similar creative support systems that have used the CSI for evaluation. A sample calculation for the CSI score can be seen in table 4.1.[6]

Category	Q1	Q2	Sum	Chosen Count	Weighted Sum
Expressiveness	8	9	17	3	51
Immersion	7	8	15	2	30
Collaboration	6	7	13	3	39
Usability	9	8	17	3	51
Feedback	7	8	15	2	30
Enjoyment	8	9	17	2	34
Total					235
CSI					$\frac{235}{3} = 78.33$

Table 4.1: Example CSI ratings with calculation

To complete the study, the users are asked to work through three tasks. The tasks were developed over various iterations of alternatives. Before explaining the tasks, it is important to define which variables can be adjusted in the drawing environment. The four noteworthy variables are speed, order of drawing, type of drawing, and drawing borders.

Firstly, the plotter's speed can be adjusted so that each g-code line can have different speeds. The drawing order is changeable; the Pen Plotter could always start, the human could always begin, or a back-and-forth can be set as a rule. The type of drawing can be changed as well, what should be the Pen Plotter draw and how should it depend on the drawing of the Human counterpart? The rules of the task can be set, which means the Pen Plotter could only draw on detected space or only draw on existing drawings. Or the Pen Plotter gets part of the paper, and the human gets the other part.

Quiet fast, it was clear that the speed was the least exciting change in the setup, making for repetitive tests. A slow-drawing Pen Plotter is uninteresting and makes for a very long study. The benefit of slow drawing is increased accuracy. The small margin of improvement doesn't make up for the time loss. The solution is a set drawing speed and a set pen movement speed when lifted. Similar to 3D printers, the speed of cornering and acceleration is critical, these values have already been adjusted through previous experience with the Pen Plotter.

Leaving the drawing order open as a variable allows the participant to decide. To keep the variable noteworthy but not the focus of the study, the order chosen will be noted for each test. Alongside the order of drawing, the turns taken will be noted. Since the user will be given the choice to start or let the Pen Plotter start, the user can choose to let the Pen Plotter draw multiple turns in a row. If this is the case it will be noted.

The last variable to be eliminated was the borders of the drawing, though it is important to note and decide where the Pen Plotter draws; after some testing, participants cared more what the Pen Plotter was drawing and not why it chose to draw on a specific spot on the paper. Also, conducting a user study purely on the position of the drawing didn't allow for much diversity.

The most obvious decision was to focus on what the Pen Plotter was drawing since this hoped to have the most significant impact on the user's creative process. The current Pen Plotter setup can draw anything, including just one color since a pen swap mechanic is not possible. Still, it would have added another level of complexity to the setup. The discarded first options included copying and tracing existing shapes, filling the detected drawing with patterns from a pre-defined list, and filling space with pre-defined elements. Even though some tests yielded good results, the three options led to the user's frustration and were easily manipulated once the user understood how the system worked. The plotter had difficulty detecting the details when drawing complex small shapes due to the webcam's resolution. When copying the user's shapes, the generated g-code does not fully represent what the user has drawn. Similar issues go for the second option; when drawing multiple alone standing elements on paper, the plotter shape detection seemed to try and find connections between the drawings and would fill big parts of the page with patterns that were empty before. This led to a fast end to the test. If the user started, the Pen Plotter often filled the space, and the test ended. Letting the Plotter fill the space with pre-defined elements is the last option, which caused the plotter to draw for very long periods if the user gave the plotter the right to start or didn't draw much themselves to be inspired by the plotter since the starting order should be open to the user. These issues need to be eliminated.

The results of these tests were taken into consideration to improve the design of the user study tests. It was decided that the study would consist of three tests; in each test of which, the Pen Plotter would draw something different. After each test, the user would fill out a questionnaire and the CSI forms necessary to make up the CSI score.

Due to safety, the plotter would not operate independently but require a button press or mouse click before each drawing cycle.

The first test, or test A, is the simplest. The script detects a key press and from then on generates randomized l-systems, the amount and length of these vary through different runs. The l-systems imitate flower petals, as shown in figure 4.5. The size and amount per drawing run had no dependencies on the user's drawing and, therefore, no connection to the user input. The script generates a vector graphic, saves it as .svg, then converts it to g-code and sends it to the g-code sequencer. Every time the plotter is asked to draw, a new graphic is generated and drawn. The starting position and position of the l-systems are also random; additionally, an offset is generated for each run to prevent the Pen Plotter from drawing over the edges. The background of a repetitive drawing, giving all users the same inspiration, was introduced to provide a uniform starting point, ensuring that every participant shared a baseline test. This controlled test was added to compare it to the later tests. Hoping for diverse results emerging from minimal inspiration and input.

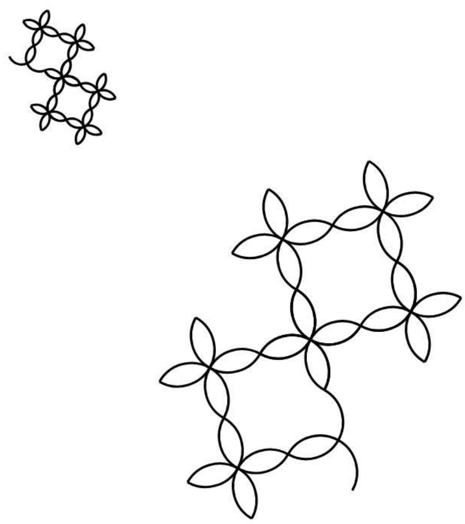


Figure 4.5: A generated l-system used in test A

The second test, or test B, is the most complex. By using an API and Machine Learning, the system increases in complexity, leading to impressive outcomes. The model is trained on the Quick, Draw![2] dataset. The training process uses a custom script that parses the dataset and leverages TensorFlow to build a model capable of recognizing and predicting user sketches.

```
train_model_AI.py
```

and the resulting model is saved as

```
quickdraw_model.keras
```

The model detects what can be seen on the drawing; the webcam image is converted to contour detection, which uses greyscale to detect lines on the paper. The Image is cut to the size of the paper and saved as a vector graphic; the trained model then returns the category with the detected probability and selects a random sketch from the NDJSON file. This is converted to a vector graphic and to g-code. The g-code is saved and sent to the g-code sequencer and is drawn by the Pen Plotter; between the detection and the beginning of the drawing, there is a small delay of about 1 - 1.5 seconds. The idea of this 'mimic' inspired run is to support the user in a direction that they are already drawing in. Or if the user lets the robot draw first to give an idea of where the sketch can lead from here.

[2] Google Inc., *Quick, Draw! Dataset*, accessed August 19, 2024, `https://quickdraw.withgoogle.com/data`

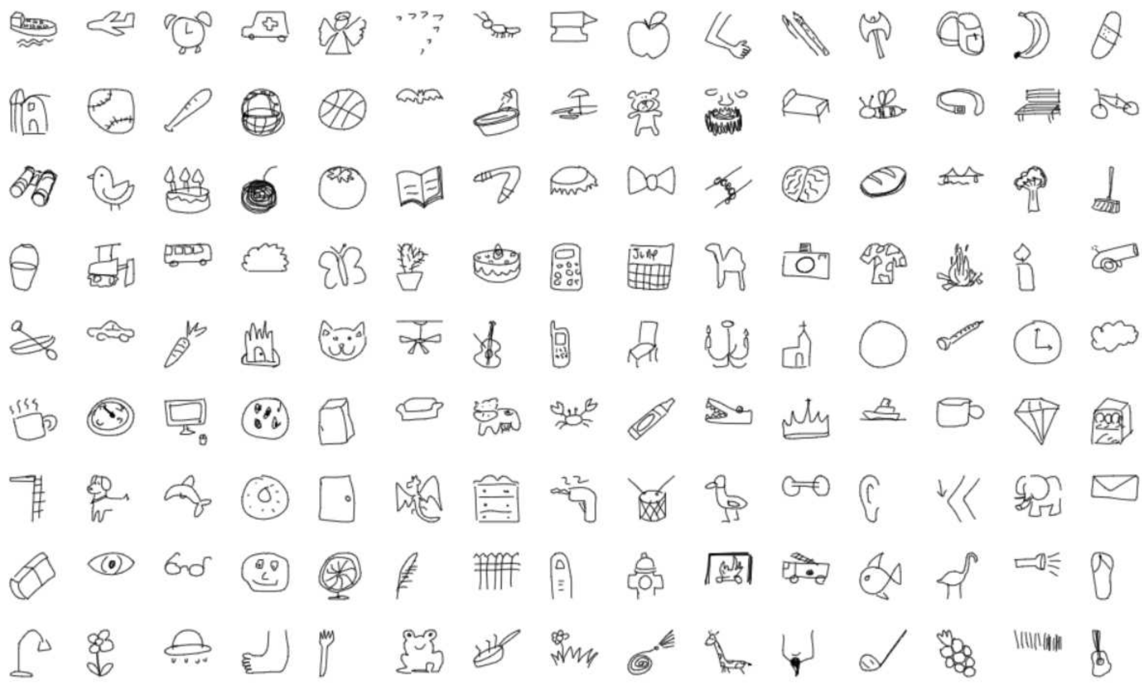


Figure 4.6: Source: Google Inc.,*Quick, Draw! Dataset* (accessed August 21, 2024, `https://quickdraw.withgoogle.com/data`).

The drawing system uses a machine learning model trained on *Google's Quick, Draw!* dataset. This dataset contains 50 million sketches categorized into 345 classes. In figure 4.6 The model is trained using the

```
train_model_AI.py
```

script, which employs the *TensorFlow*[3] framework. During training, the dataset, provided as NDJSON files, is parsed and divided into batches to manage the large size of the dataset. Each batch is split into training and validation sets, weighing 80 to 20.

The model architecture used is a Convolutional Neural Network (CNN) combined with a Recurrent Neural Network (RNN) to handle the sequential nature of the drawing strokes. The CNN extracts features from the sketch images. At the same time, the

[3]TensorFlow, *TensorFlow: Large-Scale Machine Learning on Heterogeneous Systems*, accessed August 19, 2024, `https://www.tensorflow.org/api_docs/python/tf`

RNN captures the temporal sequence of strokes, making the model effective at recognizing the patterns of hand-drawn sketches. After training, the model achieved a 63 percent accuracy and was saved as

```
quickdraw_model.keras
```

```
Training the model...
Epoch 1/10
8625/8625  12964s 2s/step - accuracy: 0.1395 - loss: 4.2813
- val_accuracy: 0.3706 - val_loss: 2.7049
Epoch 2/10
8625/8625  12543s 1s/step - accuracy: 0.4063 - loss: 2.5266
- val_accuracy: 0.4571 - val_loss: 2.2868
Epoch 3/10
8625/8625  12541s 1s/step - accuracy: 0.4867 - loss: 2.1328
- val_accuracy: 0.5002 - val_loss: 2.0927
Epoch 4/10
8625/8625  12563s 1s/step - accuracy: 0.5293 - loss: 1.9329
- val_accuracy: 0.5189 - val_loss: 2.0010
Epoch 5/10
8625/8625  12604s 1s/step - accuracy: 0.5591 - loss: 1.7915
- val_accuracy: 0.5303 - val_loss: 1.9569
Epoch 6/10
8625/8625  12552s 1s/step - accuracy: 0.5769 - loss: 1.7033
- val_accuracy: 0.5452 - val_loss: 1.8938
Epoch 7/10
8625/8625  12595s 1s/step - accuracy: 0.5917 - loss: 1.6313
- val_accuracy: 0.5566 - val_loss: 1.8564
Epoch 8/10
8625/8625  12610s 1s/step - accuracy: 0.6062 - loss: 1.5687
- val_accuracy: 0.5577 - val_loss: 1.8479
Epoch 9/10
8625/8625  12672s 1s/step - accuracy: 0.6159 - loss: 1.5265
- val_accuracy: 0.5542 - val_loss: 1.8511
Epoch 10/10
8625/8625  12863s 1s/step - accuracy: 0.6232 - loss: 1.4896
- val_accuracy: 0.5642 - val_loss: 1.8223
```

```
Saving the model to C:\Users\user\AppData\Local\Google\
Cloud SDK\quickdraw_dataset\quickdraw_dataset\model\
quickdraw_model.keras...
Model saved successfully.resulting model
```

When operating the co-creative system on a keypress or mouse press, the webcam captures the live image of the drawing, which is then converted to grayscale for contour detection. This process isolates the lines, converting the image into a clean, binary format that the model can process. The preview of this can be seen in the threshold window in figure 6.1b. The image is resized to 28x28 pixels, normalized to a [0, 1] scale, and flattened into a one-dimensional array to match the input requirements of the model. Once the image is prepared, it is passed through the trained model, which outputs a prediction of the drawing's category along with the probability score for that prediction. The system selects a random sketch from the NDJSON file based on the predicted category. This sketch is converted into a scalable vector graphic (SVG) and converted into g-code.

The g-code is sent to the g-code sequencer, which controls the Pen Plotter to draw the selected sketch on the paper. A brief delay of 1 to 1.5 seconds ensures that the transition from detection to drawing is smooth and visually pleasing, imitating a thinking process.

For the third run or test C, the QUICK, DRAW! dataset is utilized again. In this test, the user does not influence the outcome. The script randomly selects a category from the dataset and then draws a random sketch from that category, with the position on the paper also randomized. This test is added to compare tests B and C, providing a baseline against which to evaluate whether the trained model genuinely supports the user or if the dataset drives the results. The user is not informed which category was selected and must adapt to the sketch added to their image. The process from detection to g-code generation mirrors that of test B. Additionally, this test helps to assess whether users can perceive a connection between their drawing and the plotter's contribution or if they imagine one even when none exists.

4.3.1 User testing and feedback

The technical setup is placed on a table, as explained previously. The user is given a pen and asked to sit opposite the system. The Pen Plotter is oriented toward the user so that the tripod setup is behind the Pen Plotter, and the participant faces the open side of the Pen Plotter. The participant is asked to fill out a legal form and a demographic form providing personal information. Following this, the participant is given a brief overview of what the Pen Plotter does and how it works. Any questions about the system or the upcoming study are answered during the introduction to create a comfortable environment. By giving the participants time to settle in and observe the Pen Plotter and the rest of the setup, most of the discussion is conducted before the study begins, allowing the user to think freely during the drawing phase. Minimizing interaction with the participants ensures less influence on their creative process. Distractions in the room are kept to a minimum.

The core of the study consists of three phases: task explanations, drawing phase, and evaluation. Three different runs each undergo three stages, and the order of the runs is set in a predefined Latin Square[15] as seen in table 4.2.

Participant	ID	Task Order
1	54C	A B C
2	19D	B C A
3	63E	C A B
4	17F	A B C
5	72G	B C A
6	12H	C A B
7	16J	A B C
8	99K	B C A
9	80L	C A B
10	79M	A B C
11	21N	B C A
12	104P	C A B

Table 4.2: Latin Square Task Order

The Participants will be greeted with the following introduction to the test.

Thank you for being part of my study. In this study, you will test a setup for creative drawing using a Pen Plotter. I will ask you to complete multiple questionnaires for 45-60 minutes. I'd like you to answer these as honestly as possible. I will record and take pictures of the study. This data will be anonymously saved locally and only be used for the evaluation. We will be going through three different runs. Each run will be structured similarly, but the robot will behave differently in each run. No prior knowledge of robotics or drawing is needed, nor must you be creative. The structure of each round is made up as follows. I will ask if you or the robot should start drawing each round. This decision is up to you; then you can decide who will go next. You can take turns with the robot or let the robot draw multiple times. You choose the run length, and you can go back and forth with the drawing turns as long as you'd like. Please do not draw simultaneously with the robot. Let me know when you are happy with the drawing, and we will end the run. After each run, I will ask you to complete the questionnaire before we begin with the next one. Let me know if you feel uncomfortable or want to leave. Any Questions? Then, I would like you to fill out this demographic question, read this necessary paper, and sign it.

When the participant has no more questions regarding the system or the previous task, the task explanation is read out loud, as seen below.

Task A
For this task, I would like to draw on paper. Remember, you can start drawing or let the Pen Plotter start. Just let me know. You can draw anything you'd like; if you need inspiration, ask me. Please let me know whenever you want the Pen Plotter to draw and remove your hands from the drawing surface. Remember, you can go back and forth as often as you like and allow the Pen Plotter to draw multiple times. In this Task, the robot will draw pretty shapes on the paper. Whenever you would like to end the task, please let me know. Any Questions?

Task B
For this task, I would like to draw on paper. Remember, you can start drawing or let the Pen Plotter start. Just let me know. You can draw anything you'd like; if you need inspiration, ask me. Please let me know whenever you want the Pen Plotter to draw and remove your hands from the drawing surface. Remember, you can go back and forth as often as you like and allow the Pen Plotter to draw multiple times. In this Task, the Pen Plotter will utilize an AI running in the background to analyze your drawing and add

its selection to your drawing. The Pen Plotter will draw sketches from a dataset of 50 Million drawings. Whenever you would like to end the task, please let me know. Any Questions?

Task C:
For this task, I would like to draw on paper. Remember, you can start drawing or let the Pen Plotter start. Just let me know. You can draw anything you'd like; if you need inspiration, ask me. Whenever you want the Pen Plotter to draw please let me know and remove your hands from the drawing surface, remember you can go back and forth as often as you want, and allow the Pen Plotter to draw multiple times in a row. In this Task, the Pen Plotter will draw sketches from a dataset of drawings. Whenever you would like to end the task, please let me know. Any Questions?

The user will be thanked and asked to complete the last questionnaires at the end of the last task.

That is it, thank you for participating in my study, you can keep your art pieces if you want. Before you leave I would ask you to fill out one last set of questionnaires, keep in mind that the first questionnaires are regarding the test run you just did and the factor comparison and additional questions are related to the entire study. I want to ask you again to be as honest as possible. I hope you had some fun, and I would like to thank you again for taking the time to come here and work through all my questions and tasks.

5 Results and Discussion

The study was conducted over three days with a total of 12 participants. To keep the user's identity anonymous, each user is referred to by a number and a letter, for example *21n*. The findings and results are presented and analyzed in the following chapter. As previously explained, questionnaires were administered to each participant. Some questions required written responses; selected excerpts from these answers are presented below, while a complete overview of all responses is included alongside the code in the repository. The remaining questions were answered using a Likert scale of 1 to 7. The results will be analysed and discussed following an overview of the study's key findings. Furthermore, limitations and potential improvements will be discussed, offering insights for future work. The visual outcomes of the created art will be presented before the scores and results are analysed. All used questionnaires can be found in the appendix.

The participants filled out a demographic questionnaire before the study began. The results can be seen in table 5.1. Questions four, five, six, and seven can be seen below. Each question was assessed on a Likert scale from 1-7 for questions four, five, and six, 1 indicating *"No Experience"* and 7 indicating *"A lot of experience"*. For question seven, the Likert scale went from *low* to *high*.

4. How much experience do you have with co-creative systems? *This included digital co-creative systems such as Stable Diffusion, DALL-E, or anything where an AI interacts with a Human to create*

5. How much experience do you have with creative drawing? *This included physical drawing on paper or canvas and digital drawing on a tablet or digital drawing device.*

6. How familiar are you with physical Human-Robot Interactions? *This includes Industrial Robots, Home Robots like vacuum cleaning robots, educational robots, and assistive robots.*

7. How high are your expectations towards interacting with the Pen Plotter system?

The participants with little experience with co-creative systems and little experience with human-robot interactions. The study began with medium expertise in creative drawing and medium expectations towards the Pen Plotter, averaging over the participants. A mixed group with diverse backgrounds and experiences offer a good starting point for the study.

Participant	**Age**	**Gender**	**Occupation**	**Q 4**	**Q 5**	**Q 6**	**Q 7**
72G	26	Female	Digital Media	6	6	2	1
104P	23	Female	Film	4	5	6	4
21N	25	Male	Psychology	1	3	2	4
79M	54	Female	Chef	1	3	1	4
80L	26	Male	Digital Media	4	1	5	3
99K	26	Male	Conductor	1	1	2	4
16I	26	Female	Cultural Science	4	6	2	1
19D	25	Female	Integrated Design	2	5	1	4
54C	27	Male	Engineering	4	3	4	3
63E	26	Non-Binary	Security	2	5	3	5
17F	27	Male	History & English	3	2	2	4
12H	27	Male	Cultural Science	1	4	2	5
Mean				2.75	3.67	2.67	3.50
SD				1.66	1.78	1.56	1.31

Table 5.1: Demographic Questionnaire Results

5.1 Artisitc Results of the Study

In test A, the robot drew repetitive flower petals; two example results are shown in figures 5.1 and 5.2. In figure 5.1, the participant took the flowers as inspiration to add detail to the petals and include leaves and stems. The Pen Plotter started this run. After finishing their second drawing cycle, the participant stopped the test by saying, "I'm scared he will ruin it." In figure 5.2, the Pen Plotter also began the task. The Plotter ended up taking eight turns, while the participant had five. The flower petals from the robot were initially accepted and turned into flowers, inspiring a nature-themed image. However, as the Pen Plotter added more elements, the participant contributed fewer additions until the test ended. The result is a somewhat chaotic landscape.

Figure 5.1: Result from test A (CSI: 58)

Figure 5.2: Result from test A (CSI: 48.67)

More examples of test A results can be seen in 5.3, 5.4, 5.5 and 5.6.

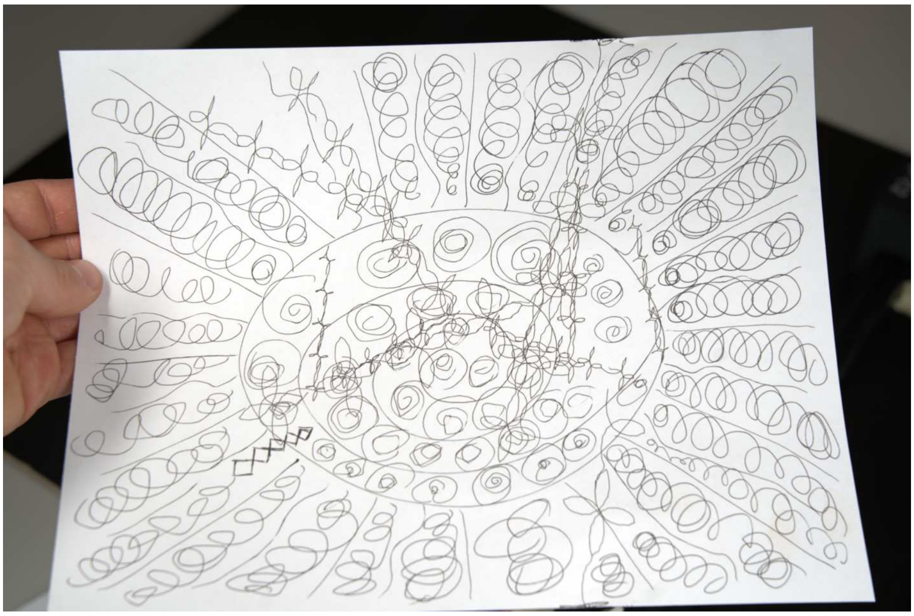


Figure 5.3: Result from test A (CSI: 48.67)

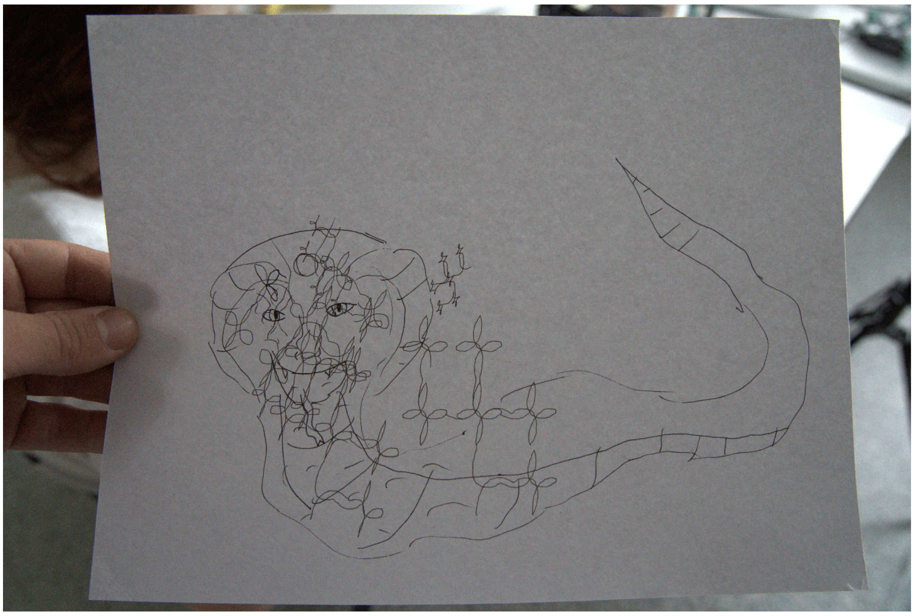


Figure 5.4: Result from test A (CSI:36)

Figure 5.5: Result from test A (CSI: 65.67)

Figure 5.6: Result from test A (CSI: 35.33)

In test B, the trained model instructed the Pen Plotter on what to draw by detecting what the participant was most likely drawing. The green highlighted areas in figure 5.7 show the Pen Plotter's drawing. The participant began this test by drawing a hedgehog in the centre of the image. The model detected the category *toothbrush* with a probability of 62.3 percent. After five turns for the participant and six turns for the Pen Plotter, the model detected *toothbrush* with a probability of 51.1 percent, *matches* with 32.1 percent, *toothbrush* with 33.8 percent (twice), and *bread* with 29.6 percent. The participant accepted the toothbrushes and created their own "Toothbrush Army".

Another example of test B can be seen in figure 5.8. The participant started the test, and the Pen Plotter, as well as the participant took three turns each. The participant began with flowers in the centre of the paper. The model then detected the category *sun* with a probability of 56 percent. The user extended the flowers, and the model detected *wine bottle* with a probability of 55.5 percent. The participant added a wine glass and a table before the model detected *flower* with a probability of 48.7 percent. The participant then added details and ended the run.

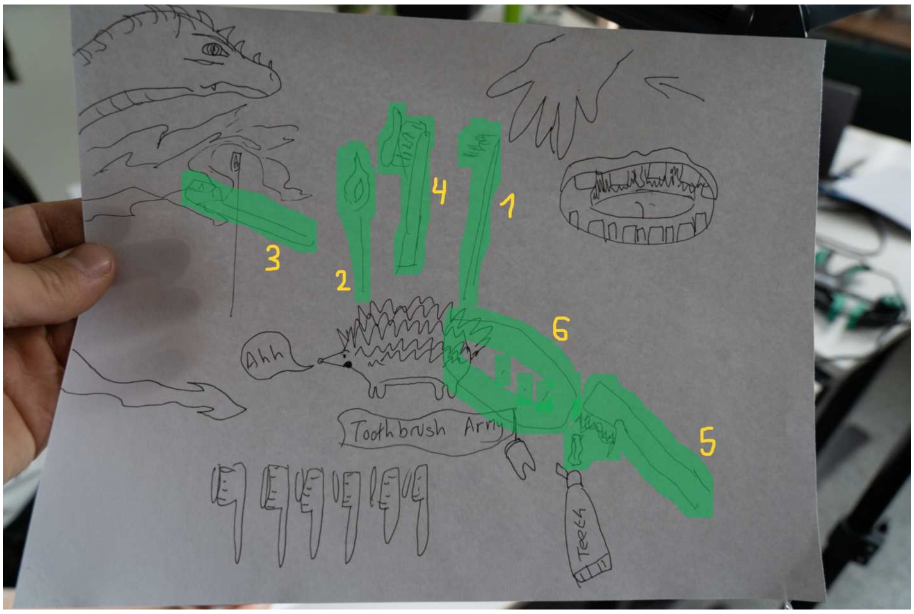


Figure 5.7: Result of test B, Pen Plotters additions in green (CSI: 78.67)

Figure 5.8: Result of test B, Pen Plotters additions in green (CSI: 33)

More examples of test B results can be seen in 5.9, 5.10, 5.11 and 5.12.

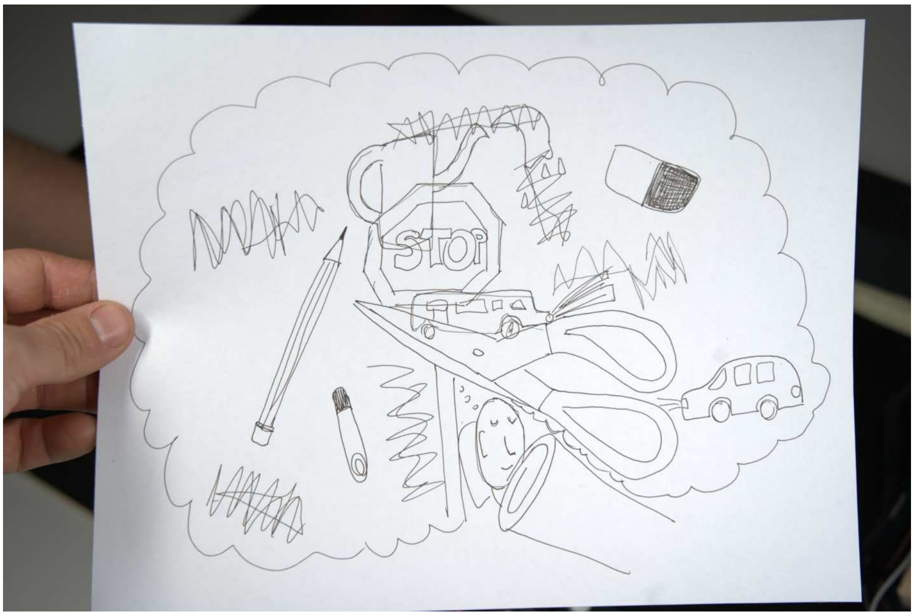


Figure 5.9: Result from test B (CSI: 72)

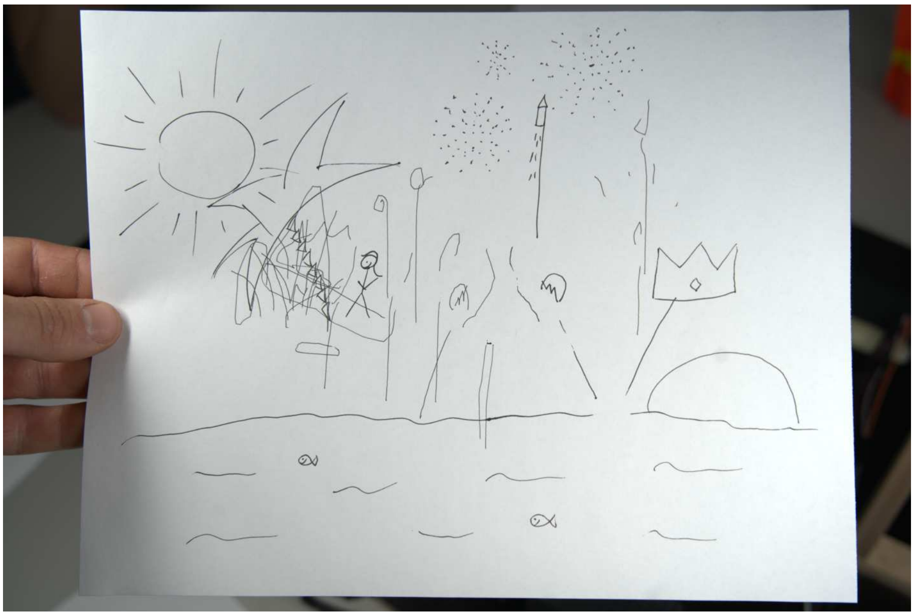


Figure 5.10: Result from test B (CSI: 56.67)

Figure 5.11: Result from test B (CSI: 34.33)

Figure 5.12: Result from test B (CSI: 83.33)

Figure 5.13 shows an example of test C's results. This specific example scored the highest individual CSI score of the entire study. The model randomly decided which category to choose and which drawing to create. The participant started this round and drew four times, while the Pen Plotter had six turns. The Pen Plotter's drawings were categorized as *1. "nose, 2. "hedgehog," 3. "candle," 4 and 5 "matches," and 6. "waterslide."*. The participant's additions resulted in an image that effectively utilized the Pen Plotter's contributions and drew inspiration from them.

Since test C was random and partly unpredictable, some results led to confusion and emotional reactions. On example of this was when the participant tried working with the Pen Plotter in figure 5.14, but the random additions overdrew existing drawings. The Pen Plotter drew *1. "whale," 2. "sailboat," 3. "wine bottle," 4. "palm tree," and finally, 5. "rain"*. The Pen Plotter started this task, took five turns, and the participant drew four times.

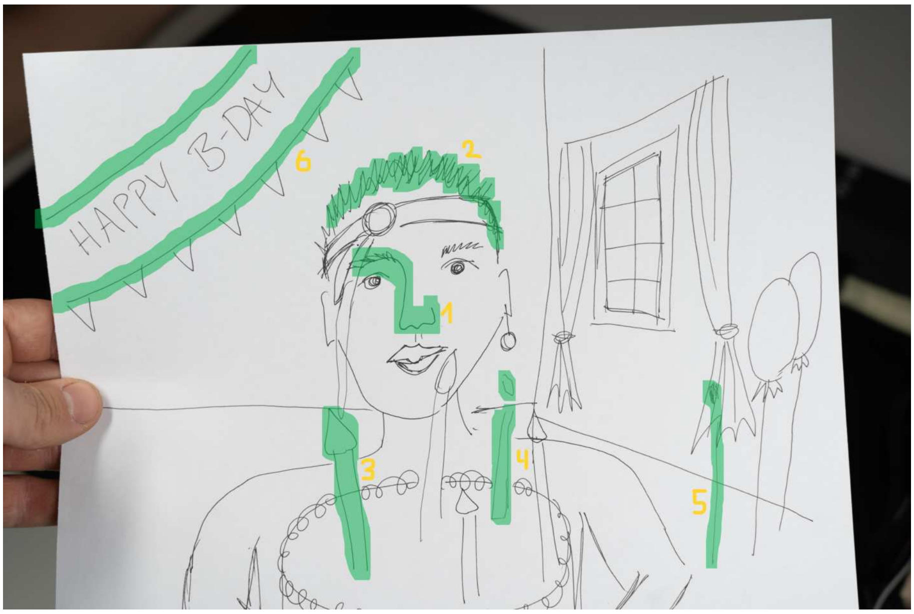


Figure 5.13: Result from test C, Pen Plotters additions in green (CSI: 86)

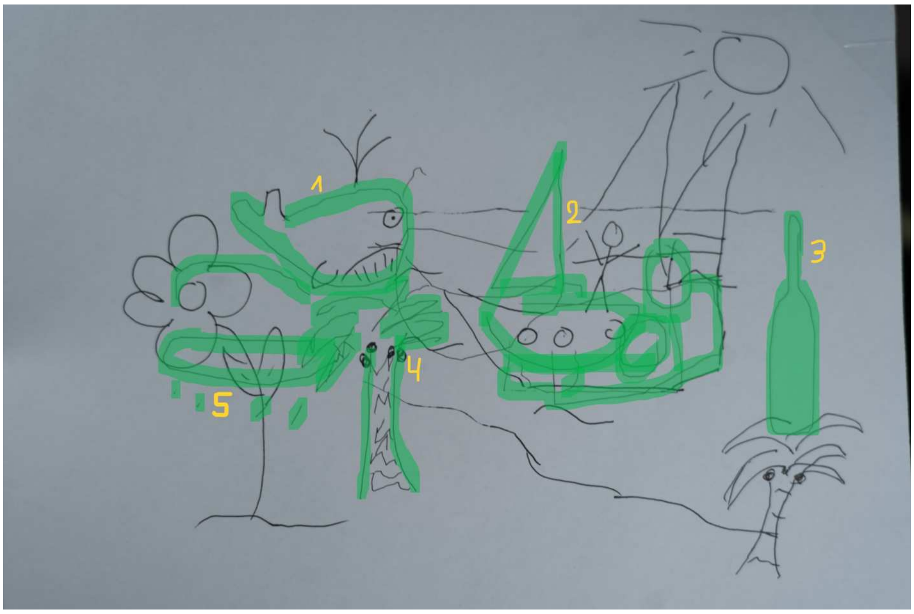


Figure 5.14: Result from test C, Pen Plotters additions in green (CSI: 39)

More examples of test C results can be seen in 5.15, 5.16, 5.17 and 5.18.

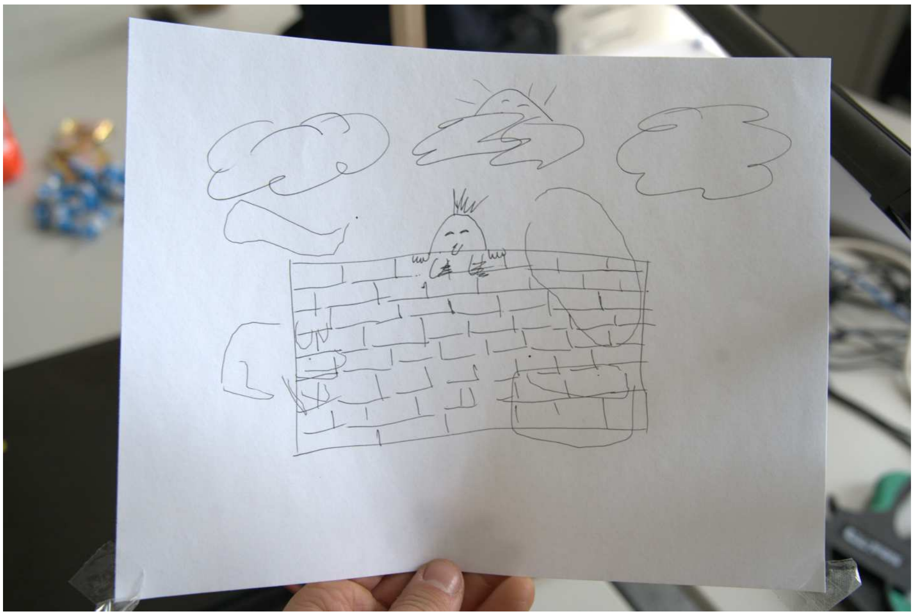


Figure 5.15: Result from test C (CSI: 38.67)

Figure 5.16: Result from test C (CSI: 79)

Figure 5.17: Result from test C (CSI: 57.33)

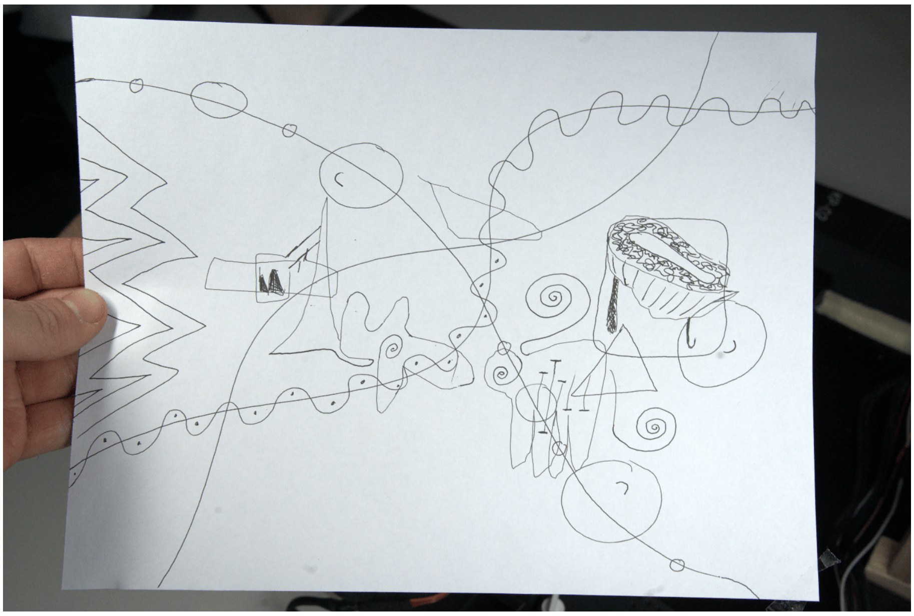


Figure 5.18: Result from test C (CSI: 41:33)

All images shown here have been chosen to represent the tasks. Every result is unique, and each participant took the tasks slightly differently than another. As art is a perceptional craft, each viewer takes in the images differently; therefore, the opinion of one might not matter to another. More results can be found in the appendix.

5.2 CSI Results

The CSI Results can be seen in Table 5.2, which shows the results of the factor comparison. Table 5.3 displays the results for Test A, while Table 5.4 presents the results for Test B, and Table 5.5 contains the results for Test C.

The factor comparison revealed the following results: the least valuable factor in this study was *Work with other people*, with an average score of 1.17 and a standard deviation of 1.8. It was clear that users prioritized the factors *Be creative and expressive*, *Enjoy using the system or tool* and *Explore many different ideas, outcomes, or possibilities*. The latter is not surprising since the exploration of co-creation was one of the system's primary goals from the beginning. This factor scored 3.5 out of 5 with a standard deviation of only 1. The factors themselves do not have fundamental value; their combination with the 12 questions calculates the CSI scores and determines the weighting of each factor. Nevertheless, displaying the results by themselves is noteworthy as it indicates what the participants valued.

CSI Factors:

- **CE**: Be creative and expressive
- **IA**: Become immersed in the activity
- **EU**: Enjoy using the system or tool
- **ED**: Explore many different ideas, outcomes, or possibilities
- **RE**: Produce results that are worth the effort I put in
- **WP**: Work with other people

Factors	99k	16i	21n	79m	80l	104p	12h	17f	63e	19d	72g	54c	Mean	SD
1. CE	3	4	2	1	3	4	5	3	2	3	2	2	2.83	1.11
2. IA	2	1	0	5	2	1	0	5	4	2	5	3	2.50	1.88
3. EU	4	5	4	4	5	3	2	2	3	4	3	3	3.50	1.00
4. ED	1	3	4	2	4	5	3	4	5	5	4	3	3.58	1.24
5. RE	0	2	1	2	1	2	2	1	1	1	0	4	1.42	1.08
6. WP	5	0	4	1	0	0	3	0	0	0	1	0	1.17	1.80

Table 5.2: CSI Factors Results

Test A	99k	16i	21n	79m	80l	104p	12h	17f	63e	19d	72g	54c	Mean	SD
Collaboration	12	20	10	6	6	8	9	4	16	11	11	8	10.08	4.46
Enjoyment	13	12	9	5	10	2	13	9	12	14	14	3	9.67	4.23
Exploration	14	3	5	5	8	6	6	5	7	15	2	2	6.50	4.17
Expressiveness	14	11	9	11	11	9	6	9	13	14	11	5	10.25	2.83
Immersion	12	3	7	14	8	8	8	3	8	6	2	13	7.67	3.89
Result Worth Effort	12	13	8	7	12	2	6	4	13	2	10	4	7.75	4.20

Table 5.3: Test A Scores by Participant (M=45.56 ; SD=11.68)

Test B	99k	16i	21n	79m	80l	104p	12h	17f	63e	19d	72g	54c	Mean	SD
Collaboration	11	19	13	8	7	17	6	4	18	18	20	8	12.42	5.78
Enjoyment	12	12	10	6	12	17	9	9	14	17	20	10	12.33	4.03
Exploration	7	13	6	7	11	13	6	3	10	20	20	4	10.00	5.67
Expressiveness	11	17	8	5	13	16	8	8	17	16	14	16	12.42	4.25
Immersion	4	6	7	10	9	16	6	8	9	2	2	16	7.92	4.58
Result Worth Effort	15	13	8	5	15	16	7	4	14	15	15	14	11.75	4.41

Table 5.4: Test B Scores by Participant (M=58.75 ; SD=20.47)

Test C	99k	16i	21n	79m	80l	104p	12h	17f	63e	19d	72g	54c	Mean	SD
Collaboration	15	19	12	8	6	18	12	4	17	7	20	9	12.25	5.50
Enjoyment	15	15	11	6	13	11	18	9	14	14	10	11	12.25	3.22
Exploration	14	18	8	8	5	10	14	7	13	17	3	5	10.17	4.95
Expressiveness	16	19	8	9	12	20	17	10	14	10	2	14	12.58	5.14
Immersion	18	10	7	9	7	12	7	6	7	6	2	16	8.92	4.50
Result Worth Effort	17	18	12	10	9	12	17	8	13	11	3	16	12.17	4.41

Table 5.5: Test C Scores by Participant (M=58.11 ; SD=17.55)

Each of the three tests has its own CSI Score. The comparison of the CSI scores is shown in Figure 5.19. As expected, the repetitiveness of test A resulted in the lowest creative support score average. No participant ranked Test A as their highest score. While Test A resulted in the lowest average CSI score (M = 45.56, SD = 11.68), indicating lower creative support, tests B and C scored similarly (B: M = 58.75, SD = 20.47; C: M = 58.11, SD = 17.55). Test A's structure gave users more control, leading to higher satisfaction in task completion but lower creative support. In contrast, test B, which featured dataset-based contributions from the Plotter, encouraged greater creative exploration and introduced unpredictability, leading to mixed responses in user engagement. Test C's fully randomized elements resulted in the highest creativity exploration, though some users expressed frustration with the lack of control over the robot's contributions. The relatively high SD scores in tests B and C and the individual ratings suggest that the model and dataset may have some flaws.

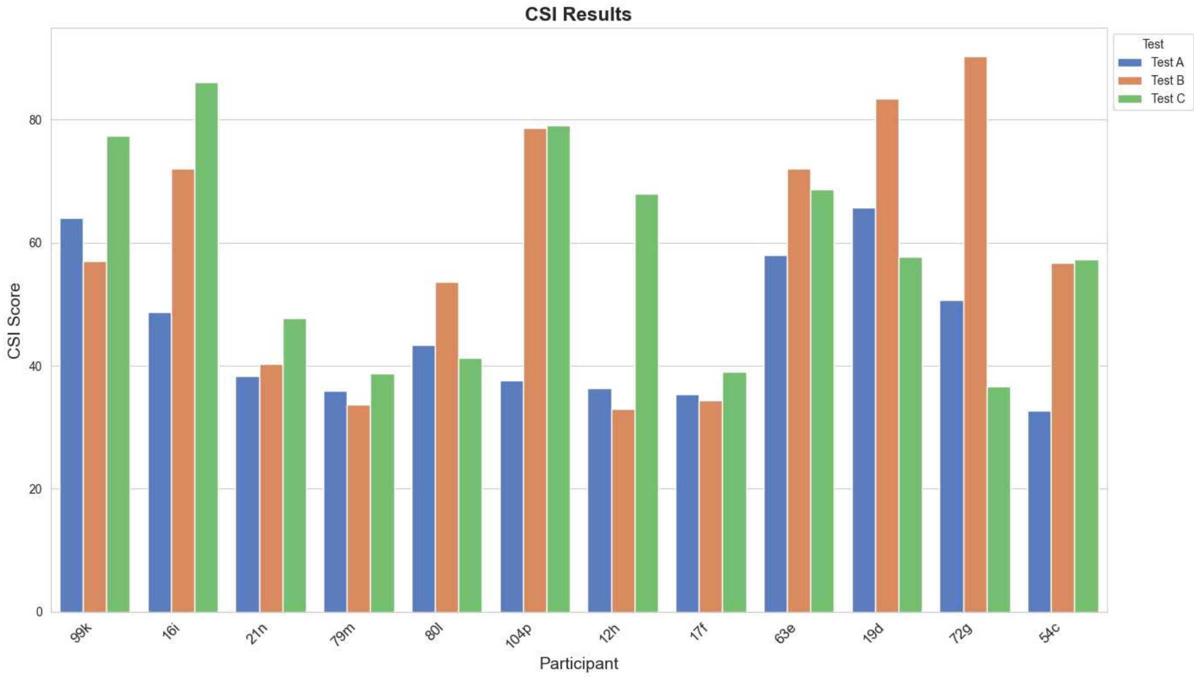


Figure 5.19: A comparison between the CSI Scores between the tests

5.3 Statistical Analysis

The *Wilcoxon signed-rank test* was employed to understand the results of the CSI. This non-parametric test is suitable for comparing two related samples when the data does not necessarily follow a normal distribution. It provides an alternative to the paired t-test, which assumes parametric data. Typically, for comparing three paired groups, the test is conducted pairwise between each pair of groups: Test A vs. Test B, Test A vs. Test C, and Test B vs. Test C. The *Wilcoxon signed-rank test* outputs three values.

A test *statistic* ranks the differences between pairs and sums these ranks. A lower statistic in this context suggests a deviation in the observed scores.

A *P-value*, reflecting the probability that observed differences statistically exist between the test conditions. A p-value below 0.05 suggests that the differences observed are statistically significant and unlikely to have occurred by random.

An *effect size (r)*, measuring the magnitude of the difference, normalized to the number of observations. An r value closer to 1 indicates a stronger effect, indicating that the variations in the test conditions had a notable impact on the outcomes. [20]

```
Test A vs. Test B:
Statistic: 13.0
P-value: 0.04248046875
Effect Size (r): 0.5856590039241587
```

This result shows an increase in participant interaction in Test B compared to Test A, suggesting that the modifications in Test B had a positive impact.

```
Test A vs. Test C:
Statistic: 13.0
P-value: 0.04248046875
Effect Size (r): 0.5856590039241587
```

Similar to Test B, Test C showed variations from Test A, underlining that the changes affected participant interactions.

```
Test B vs. Test C:
Statistic: 32.0
P-value: 0.6220703125
Effect Size (r): 0.1422932581338108
```

Unlike the other comparisons, no notable difference indicates minimal practical difference in CSI scores between Tests B and C.

The analysis of test conditions within the co-creative system demonstrated that variations in drawing styles influence the level of creative support provided. These significant differences, especially the strong impact of the effect size results, suggest that task modifications have substantially altered participant engagement.

5.4 Task Initiation and Turn Dynamics

After introducing the task, participants were asked whether they want the Pen Plotter to start or prefer to start themselves. The results of this choice can be seen in Table 5.6. Even though this was not intended to be a primary focus of the study, it seemed important to note as part of the observation. Additionally, the number of turns per task is recorded during the observation process. These results are also shown in Table 5.7. Participants preferred to start the tasks themselves, with users initiating 72.22 percent of the tasks. This suggests that participants wanted to maintain control over the direction of the run. This preference is especially clear when looking at each participant's first task: only one participant chose to let the Pen Plotter start, while all other participants opted to begin themselves.

The number of turns does not seem to be influenced by which party started the task; both short and long runs occurred in either scenario. Specifically, the average total number of turns per test run, including both Pen Plotter and human turns, was 8.42 when the human started. In contrast, the average was 7.5 turns per run when the Pen Plotter started.

ID	Test A	Test B	Test C
54C	Human	Human	Pen Plotter
19D	Human	Human	Pen Plotter
63E	Pen Plotter	Human	Human
17F	Human	Human	Pen Plotter
72G	Human	Human	Pen Plotter
12H	Human	Human	Human
16I	Pen Plotter	Human	Human
99K	Human	Human	Pen Plotter
80L	Pen Plotter	Human	Human
79M	Human	Pen Plotter	Human
21N	Human	Human	Human
104P	Pen Plotter	Human	Human

Table 5.6: Decision making on starting each Task

A quick reminder that the results seen in 5.6 are sorted by tests. The Latin square order defined the participant's task order.

ID	Test A		Test B		Test C	
	Pen Plotter	Human	Pen Plotter	Human	Pen Plotter	Human
54C	3	3	3	3	2	1
19D	2	3	3	3	3	3
63E	2	2	3	2	3	2
17F	6	4	6	3	5	4
72G	5	5	8	8	10	6
12H	3	2	3	3	3	4
16I	8	5	4	3	6	4
99K	4	3	6	4	5	4
80L	3	2	5	6	3	2
79M	3	2	3	2	3	2
21N	8	7	9	3	10	7
104P	3	2	6	5	4	4

Table 5.7: Turns taken per task by Human and Pen Plotter

5.5 User Perceptions

The additional questionnaire at the end of the study was designed to gather feedback on the user experience, including thoughts on the system and suggestions for improvement. Each participant answered six questions:

1. Which other tasks could you imagine using the Pen Plotter for?
2. Which group of users would most enjoy using this setup?
3. How could the setup with the Pen Plotter be improved?
4. How do you think the Pen Plotter drawing depends on your drawing? Do you know how it works?
5. If you have past drawing experience, how do you compare this to other drawing experiences?
6. Would you use this system privately?

The answers to all questions can be found in the digital repository. Evaluation questions three and four are the most interesting. Question three asked for critical feedback and responses. The most noteworthy answers included: *"more colors," "bigger paper," "a more intelligent AI," "direct feedback—I want to know what it thinks and if it understands me," "bigger database? Or smaller? / Different one."* This feedback highlights areas for improvement. For instance, a multicolor setup could be achieved with a pen-swapping mechanism, which is likely to be implemented in a future setup and was considered in the planning stage. The criticisms related to the dataset and the trained model align with the lower CSI scores and the confusion observed in some test runs, where users felt less supported and more challenged by the Pen Plotter's drawings, which sometimes seemed randomized. A more accurate model would likely resolve some of these issues.

To determine if users understood how the detection and response process worked question four was added. The most noteworthy responses included: *"I think it tracks the pen movement I make and then tries to figure out what I drew," "analyzing structures of my drawing and comparing them to the database," "It tries to identify motifs and either recreate them or complement them. If I start the drawing, it might be more dependent," "I tried to understand the patterns, but it just didn't work out," "I think it was following the shapes of what I was drawing," "I don't know," "It is confused by its addition," and "Maybe it tries to understand what I'm drawing."* These responses indicate that the trained model can be improved, and there is a clear demand for a more transparent system in which users have insight into the process hidden during this study. Participants highlighted the need for a more refined dataset, as the randomness of the QuickDraw dataset sometimes led to outputs that didn't align with their artistic intent. This mismatch often confused, with some users feeling less supported by the system. A dataset that matches user expectations for certain artistic styles could improve the system's satisfaction. Future studies should explore whether datasets focused on specific art genres or drawing techniques would enhance user engagement and reduce the frustration caused by irrelevant outputs.

The system gained positive feedback for its approach. However, over half the participants mentioned they would not use it privately, citing the complexity and unpredictability of the plotter's responses as factors. They recommend it for specific groups such as children, artists, and digital enthusiasts. The system's interactive and co-creative elements support creative exploration for these users, making it ideal for workshops, educational programs, and group settings where learning and experimentation are prioritized. Indicating that while there is a market for the system, it is not suited for everyday use. In response to question one, participants suggested other potential tasks for the Pen Plotter, such as *"games with friends," "creating art," "printing drawings," "drawing challenges," "writing text," "technical drawings," and "helping people start drawing."* Considering these suggestions, future versions of the system could explore various directions: a playful approach featuring games like tic-tac-toe and a more artistic approach where the Pen Plotter draws mesmerizing shapes selected by users beforehand for a co-creative experience.

The comparative analysis of user feedback across the three tasks shows a clear trend. Test A's repetitive structure allowed participants to feel more ownership over the final product. However, this came at the cost of creative variability, with users feeling restricted in their artistic expression. Test B offered a balance between control and randomness, giving higher expressiveness scores (M = 12.42) while maintaining moderate user satisfaction. Test C, characterized by complete randomness, presented the highest level of creative exploration, but the lack of control led to lower satisfaction for users who preferred more structured tasks.

6 Conclusion and Future Work

6.1 Conclusion

To answer the technical research question posed at the beginning of this paper, *How can a cooperative drawing system using an Arduino-based Pen Plotter be optimized for precise tracking and drawing between human and robot inputs?* The answer remains unclear. Achieving precise tracking without interfering with the drawing process proved to be a greater challenge than expected. Initial attempts to track the pen using the Ultralytics YOLO model for multi-object tracking [1] indicated that detecting when the user draws and identifying strokes was feasible. However, a precise detection system or a second camera would be required because the pen tip only needs to vary in height by millimetres to distinguish between drawing and non-drawing states. Throughout the development, it became evident that a simpler setup allowed for a clearer focus on the task at hand, enhancing the creative process rather than achieving precise tracking. This is why the tracking attempt is not mentioned in the development process. While not as flexible as live tracking, the later implemented contour detection provided the most accurate out of the possible results. Figure 6.1b shows line detection on paper. By manually adjusting the threshold according to the room's lighting, contours can be precisely detected and converted into vector graphics or G-code, facilitating fast interaction with the TensorFlow model. The function

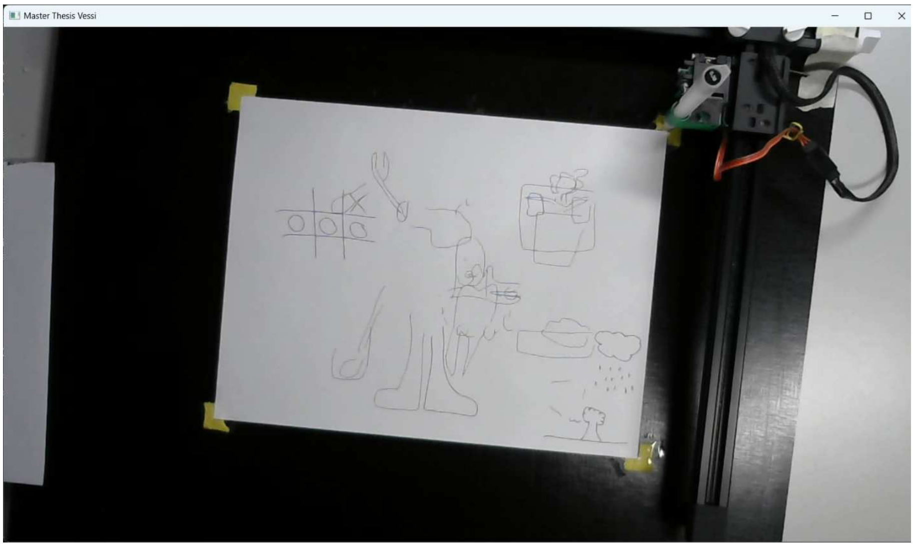
```
camera_to_plotter(point, transformation_matrix)
```

resolved the conversion issue between coordinate systems using the

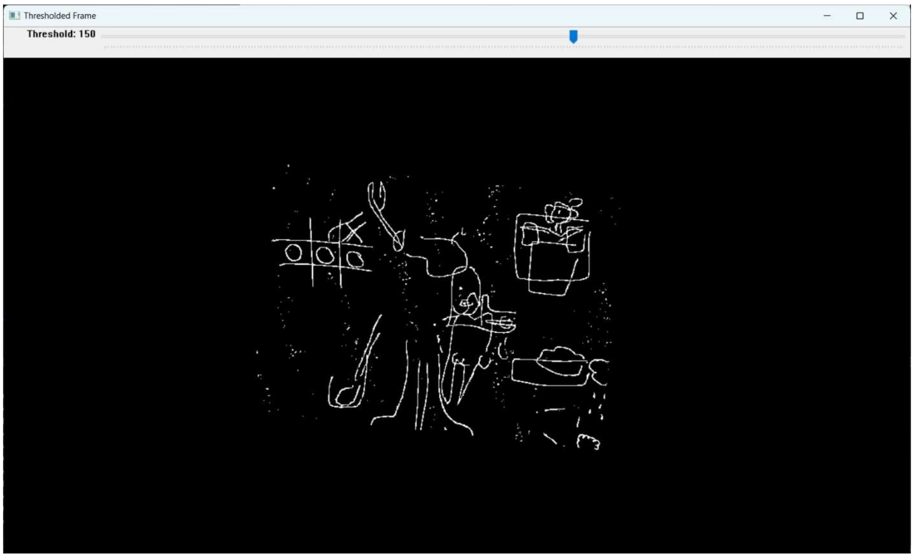
```
transformation_matrix
```

[1] Ultralytics, *Track Mode*, accessed August 22, 2024, https://docs.ultralytics.com/de/modes/track/

calculated during the program's calibration phase.



(a) Webcam view during the study



(b) View of the detection screen

Figure 6.1: Screenshots from the study: Webcam and detection views

To answer the question, it is clear that improvements are always possible. While the current 720p setup has demonstrated good results, further camera resolution and processing speed improvements should be considered. Hypothetically, reducing the latency between user input and Pen Plotter output could increase the system's precision yet not significantly impact the user's creative satisfaction. This hypothesis could be tested by comparing low-latency, high-precision systems to the current setup, focusing on user engagement and creative support.

A more thoughtful question might be: *How does the co-creative sketching setup benefit from enhanced software with improved tracking and drawing capabilities?* This question remains for future research.

Introducing a robot co-creator as a Pen Plotter significantly alters the traditional understanding of authorship in art. Participants in the study declared varying degrees of ownership over the final artwork, often depending on the level of control they felt during the creative process. Participants reported a diminished sense of authorship when the robot introduced random elements. This highlights a key challenge in co-creative systems: determining whether and how the presence of a robot co-creator influences perceptions of authorship.

According to the findings, the degree of the robot's involvement can affect users' sense of ownership. The results reveal that the type of drawing plays a role in creative support. CSI scores for tests A and B indicate that creative support is higher when the drawings are more interesting and image-related. This is further corroborated by results from question 2 of the After Task Questionnaire, where participants reported feeling more supported when the plotter actively collaborated with them, as shown by a mean score of M = 2.25 (SD = 1.06) for test A and a higher M = 3.83 (SD = 1.75) for test B. These findings suggest that participants felt more creatively supported when the Pen Plotter engaged with their input rather than operating independently and disregarding their contributions.

6.2 Reflections on the Co-Creative System

This study has introduced the design and development of a co-creative system that integrates a human artist with a Pen Plotter, contributing to the field of human-robot interaction and collaborative art creation. It was found that the co-creative process aided by the Pen Plotter not only supports the creative process but also improves the creative output. However, the debate on authorship and ownership remains unclear.

The Pen Plotter's iterative development and the insights gained from user feedback have highlighted both the potential and the current limitations of such systems. The Pen Plotter can generate unique and intricate designs, but its mechanical limitations and the built-in volatility in drawing precision present challenges that need further refinement in software and hardware.

The findings support the importance of a seamless integration of human intuition and robotic precision in co-creative systems. Future research should focus on improving the hardware of the Pen Plotter and research additional datasets, algorithms, drawing styles, and other variables for co-creation. Additionally, conducting more extensive user studies is essential to better understand the implications of human-robot collaboration in artistic contexts and to potentially provide insight into authorship perception as well.

The differing results between tests A, B, and C suggest that the system's balance between control and unpredictability significantly impacts user satisfaction and creativity. Users who preferred structure and control gravitated toward test A, where predictability allowed them to shape the outcome more directly. Those open to creative exploration appreciated test C's random elements, which gave spontaneous creativity but at the cost of frustration. In some cases, future work could explore hybrid approaches that allow users to toggle between structured and random contributions to meet users' preferences. The user would decide for themselves rather than being presented with an option without knowing what was chosen.

The statistical significance highlighted by the *Wilcoxon signed-rank test*, with effect sizes indicating a strong impact and low p-values confirming the unlikely randomness of these outcomes, underscores the observed trends. Participants gave higher satisfaction and creative support scores in tests B and C, aligning with the findings of the test.

6.3 System Limitations and Potential for Improvement

As expected, the system is not flawless. Several limitations were identified in this study, including issues related to the study design and some mechanical and software constraints. The study was conducted with only 12 participants, which may not be representative enough to generalize the results. A larger sample size would provide more robust and generalizable findings. Due to the small sample size, this study focused on a specific art style. Future research should explore a broader range of artistic styles to evaluate the robot's versatility and creativity across different genres.

The limitations of the QuickDraw dataset, which includes broad categories such as ‘ceiling fan’ or ‘zigzag’, became apparent during testing, as these random outputs often did not align with participants’ goals. The participant feedback suggests that while the randomization introduced by the QuickDraw dataset encouraged exploration, it also introduced unnecessary complexity. In particular, users noted that randomness outside of their expected outcomes hindered the creative process. Future iterations should use art-specific datasets that narrow down the randomness and better align with the users’ art style. For instance, utilizing datasets focused on abstract art, geometric shapes, or stylistic themes could provide a more supportive co-creative experience, improving user satisfaction. The Likert scale provides structured feedback from participants, but additional interviews could offer deeper insight into their perceptions and experiences.

While functional, the custom-built Pen Plotter is not as robust or precise as industrial-grade equipment, which affected the study’s accuracy and consistency. The underlying software also has limitations. Although optimizing the tracking and drawing processes was a high priority, the system is still in development. Occasional glitches and system errors restrict the system’s responsiveness and reliability. The device used to train the model for tests B and C lacked the necessary GPU and capabilities to achieve the desired accuracy and reliability.

Software and hardware limitations also restricted interaction to a one-on-one experience. Future research could explore more complex interactions involving multiple Pen Plotters with different models or drawing styles. This could include giving each Pen Plotter unique characteristics, such as various pen colors or art mediums like watercolor, acrylic paint, or ink, or enabling multiple users to interact with a single co-creative system.

Some participants expressed concerns about the system’s complexity and unpredictability, making it less suitable for personal, everyday use. However, this unpredictability can be a potential strength when prioritising experimentation and exploration. Future versions of the system could benefit from offering a simplified interface for private users while keeping the dynamic, exploratory features that make it ideal for group settings, such as art workshops or educational contexts aimed at supporting creativity in children and enthusiasts.

Although the 720p camera was chosen to balance resolution and processing time, future research should explore the impact of using a higher-resolution camera coupled with more efficient processing techniques (GPU-based processing). A comparative study between low-latency systems with varying resolutions could help identify whether these improvements significantly affect user satisfaction and creative support.

6.4 Thoughts on future work

Building on this study's findings and limitations, the proposal for future work is as follows. While previous sections discussed potential improvements and new study concepts, I propose further exploration with a user-interactive focus, where the interaction with the Pen Plotter becomes the primary subject. The emotions and actions caused by the Pen Plotter varied significantly among participants but were not the main focus of this paper. A study centred on these interaction dynamics could yield new insights into human-robot co-creation.

Future iterations of the co-creative system could incorporate a multi-pen feature, allowing the Pen Plotter to switch colors or pen types. This would significantly enhance the artistic variability of outputs, particularly in settings where users prefer directing the Pen Plotters choices instead of manually changing pens. Improving the system's mechanical stability and precision is also essential. Higher-quality materials and more advanced motor control systems could provide a more professional and reliable experience. Such refinements would make the system more suitable for casual, user-friendly environments, giving users more freedom to explore creativity.

Additionally, software improvements could enable the system to support different artistic mediums, expanding beyond the current pen-and-paper framework. By modifying the Plotter for other styles or materials, future studies could explore a broader range of creative outputs.

Future developments should consider adjustments for specific user groups. A simplified mode could make the system more accessible for private users while retaining advanced, creative features for workshops. This system could greatly benefit educational settings, where children and artists are encouraged to adapt to the Plotter's unpredictability. Providing adjustable levels of randomness would allow users to adjust the experience to their preferences, whether they seek more control or spontaneity.

Future research could also investigate using other datasets aligned with different themes. This could improve the relevance of the Plotter's contributions and help avoid the mismatch between user intent and the randomness of current datasets. Introducing datasets or allowing users to control the level of randomness could offer a more meaningful co-creative experience.

An important area for future exploration involves the ethical implications of co-creative systems, particularly concerning ownership and authorship. As the Plotter's autonomy increases, participants may feel less ownership over the final artwork, especially when the machine makes independent creative decisions. A testable hypothesis could explore whether varying levels of autonomy affect users' sense of authorship. The research could measure participants' responses to these changing variables by conducting experiments with different input levels.

As demonstrated in this study, the symbiotic relationship between humans and machines shows immense potential for artistic expression. Co-creation with robotic counterparts can lead to innovative and unexpected outcomes. Even if such systems simply encourage more engagement with artistic practices, that alone is a valuable achievement. Additionally, this research could inspire further exploration into the history of Pen Plotters and analog computers, bridging the gap between digital and physical art forms.

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Appendix

Study Questionnaire and Additional Drawing Results

Data Protection Declaration

Master Thesis User Study Participation

Researcher: Kilian Robert Dennis Vesshoff
Contact Information: vesshoff@uni-bremen.de
Institution: University of Bremen
Date:

Dear Participant,

Thank you for agreeing to participate in my master thesis user study. This study aims to investigate the effectiveness and user experience of a human-robot cooperative drawing system. Your participation is highly valued, and your data protection and privacy are paramount. This declaration outlines how your data will be collected, used, and protected.

Data Collection

1. **Personal Data:** No personal data that can directly identify you will be collected.
2. **Anonymized Data:** Data collected during the study will be anonymized. This means that all responses and data points will be stripped of any information that could link them back to you as an individual.
3. **Photographs:** Photographs will be taken during the study. These images will be used in the thesis and related publications.

Data Usage

1. **Purpose:** The data collected will be used exclusively to complete my master thesis, Sketching Together: Designing a co-creative system with a Pen Plotter, and related academic publications.
2. **Storage:** All data, including photographs, will be stored securely on my local computer.
3. **Publication:** Anonymized data and selected photographs may be included in the final thesis, which will be published and accessible to the public.

Data Protection

1. **Local Storage:** All data will be stored on my local computer, protected by encryption and secure access controls.
2. **Anonymity:** Any identifying information will be removed from the data to ensure your anonymity.
3. **Access:** Only I, Kilian Robert Dennis Vesshoff, can access the raw data. The anonymized data in the thesis will be shared with my academic advisors and may be included in scholarly publications.

Rights of the Participants

1. **Voluntary Participation:** Participation in this study is voluntary. You may withdraw from the study at any time without any consequences.

2. **Right to Information:** You have the right to request information about the data collected from you at any time.

3. **Right to Withdraw:** You can withdraw your consent to use your data at any time, and your data will be deleted.

Photographs

1. **Photographs:** Photographs will be taken during the study to document the process and results. These images will be used in the thesis and related publications.

2. **Anonymity:** All photographs will be anonymized to protect your identity. The images will not include identifiable features unless explicit consent is provided.

3. **Usage:** The photographs will be used exclusively to complete my master thesis and related academic publications.

4. **Storage:** All photographs will be stored securely on my local computer, protected by encryption and secure access controls.

By signing below, you acknowledge that you have read and understood the data protection declaration and agree to participate in the study under the above-mentioned terms.

Participant's Name: ______________________________
Signature: ______________________________
Date: ______________________________

If you have any questions or concerns about this study or your data, please do not hesitate to contact me at vesshoff@uni-bremen.de

Thank you for your participation.

Sincerely,
Kilian Robert Dennis Vesshoff
University of Bremen

Demographic Questionnaire

Please fill out the following demographic information. Your responses will be kept confidential and used only for this study.

Participant Information

1. **Age (Leave Blank if you don't want to share it):** ______
2. **Gender:**
   - ___ Male
   - ___ Female
   - ___ Non-binary
   - ___ Prefer not to say
3. **Field of Study/Occupation:** ______________________

4. **How much experience do you have with co-creative systems?**
   This included digital co-creative systems such as Stable Diffusion, DALL-E, or anything where an AI interacts with a Human to create

   1 (No Experience) — 7 (A lot of Experience)

   1 2 3 4 5 6 7

5. **How much experience do you have with creative drawing?**
   This included physical drawing on paper or canvas and digital drawing on a tablet or digital drawing device.

   1 (No Experience) — 7 (A lot of Experience)

   1 2 3 4 5 6 7

6. **How familiar are you with physical Human-Robot Interactions?**
   This includes Industrial Robots, Home Robots like vacuum cleaning robots, educational robots, and assistive robots.

   1 (No Experience) — 7 (A lot of Experience)

   1 2 3 4 5 6 7

7. **How high are your expectations towards interacting with the Pen Plotter system?**

   1 (low) — 7 (high)

   1 2 3 4 5 6 7

Please rate your agreement with the following statements:

The system or tool allowed other people to work with me easily.

1 (Strongly Disagree) 10 (Strongly Agree)

1 2 3 4 5 6 7 8 9 10

It was really easy to share ideas and designs with other people inside this system or tool.

1 (Strongly Disagree) 10 (Strongly Agree)

1 2 3 4 5 6 7 8 9 10

I would be happy to use this system or tool on a regular basis.

1 (Strongly Disagree) 10 (Strongly Agree)

1 2 3 4 5 6 7 8 9 10

I enjoyed using the system or tool.

1 (Strongly Disagree) 10 (Strongly Agree)

1 2 3 4 5 6 7 8 9 10

It was easy for me to explore many different ideas, options, designs, or outcomes, using this system or tool.

1 (Strongly Disagree) 10 (Strongly Agree)

1 2 3 4 5 6 7 8 9 10

The system or tool was helpful in allowing me to track different ideas, outcomes, or possibilities.

1 (Strongly Disagree) 10 (Strongly Agree)

1 2 3 4 5 6 7 8 9 10

I was able to be very creative while doing the activity inside this system or tool.

1 (Strongly Disagree) 10 (Strongly Agree)

1 2 3 4 5 6 7 8 9 10

The system or tool allowed me to be very expressive.

1 (Strongly Disagree) 10 (Strongly Agree)

1 2 3 4 5 6 7 8 9 10

My attention was fully tuned to the activity, and I forgot about the system or tool that I was using.

1 (Strongly Disagree) 10 (Strongly Agree)

1 2 3 4 5 6 7 8 9 10

I became so absorbed in the activity that I forgot about the system or tool that I was using.

1 (Strongly Disagree) 10 (Strongly Agree)

1 2 3 4 5 6 7 8 9 10

I was satisfied with what I got out of the system or tool.

1 (Strongly Disagree) 10 (Strongly Agree)

1 2 3 4 5 6 7 8 9 10

What I was able to produce was worth the effort I had to exert to produce it.

1 (Strongly Disagree) 10 (Strongly Agree)

1 2 3 4 5 6 7 8 9 10

1 For each comparison, choose one of the two Factors. Which of the Factors was more important to you while doing the Tasks?

☐	Be creative and expressive	**OR**	Become immersed in the activity	☐
☐	Be creative and expressive	**OR**	Enjoy using the system or tool	☐
☐	Be creative and expressive	**OR**	Explore many different ideas, outcomes, or possibilities	☐
☐	Be creative and expressive	**OR**	Produce results that are worth the effort I put in	☐
☐	Be creative and expressive	**OR**	Work with other people	☐
☐	Become immersed in the activity	**OR**	Enjoy using the system or tool	☐
☐	Become immersed in the activity	**OR**	Explore many different ideas, outcomes, or possibilities	☐
☐	Become immersed in the activity	**OR**	Produce results that are worth the effort I put in	☐
☐	Become immersed in the activity	**OR**	Work with other people	☐
☐	Enjoy using the system or tool	**OR**	Explore many different ideas, outcomes, or possibilities	☐
☐	Enjoy using the system or tool	**OR**	Produce results that are worth the effort I put in	☐
☐	Enjoy using the system or tool	**OR**	Work with other people	☐
☐	Explore many different ideas, outcomes, or possibilities	**OR**	Produce results that are worth the effort I put in	☐
☐	Explore many different ideas, outcomes, or possibilities	**OR**	Work with other people	☐
☐	Produce results that are worth the effort I put in	**OR**	Work with other people	☐

1 After Task Questions

1. **To what extent, do you think, did the pen plotter's drawing dependent on your drawing?**

   1 (not dependent) 7 (dependent)

   1 2 3 4 5 6 7

2. **Which aspects, do you think, of your drawing influenced the Pen Plotters drawing?**

3. **How creatively supported did you feel while creating with the Pen Plotter?**

   1 (not feeling creative) 7 (feeling very creative)

   1 2 3 4 5 6 7

4. **Does knowing that the Pen Plotter will draw after you, influence your creative process while drawing? If so, how? If not, why?**

5. **How much do you feel like being the Image's creator?**

   1 (not feeling like the creator) 7 (feeling like the creator)

   1 2 3 4 5 6 7

6. **Why do you feel like the creator of the Image, or why do you not feel like the creator of the image?**

7. **How satisfied are you with the interaction?**

1 (not satisfied) 7 (very satisfied)

1 2 3 4 5 6 7

8. **Based on the previous Questions? Why or why are you not satisfied with the result?**

2 Additional Questions

1. **Which other Tasks could you Imagine using the Pen Plotter for?**

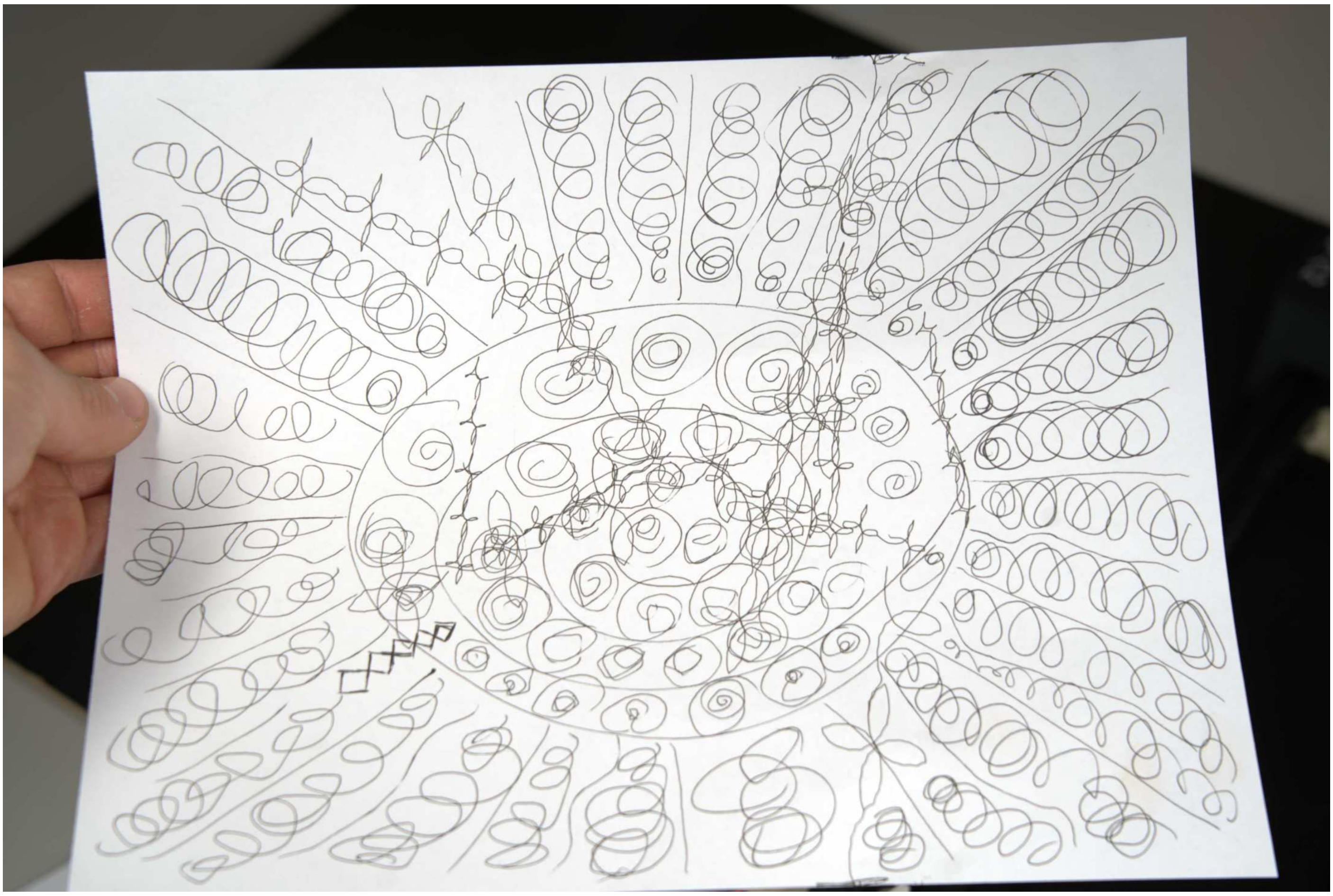
2. **Which group of users would most enjoy using this Setup?**

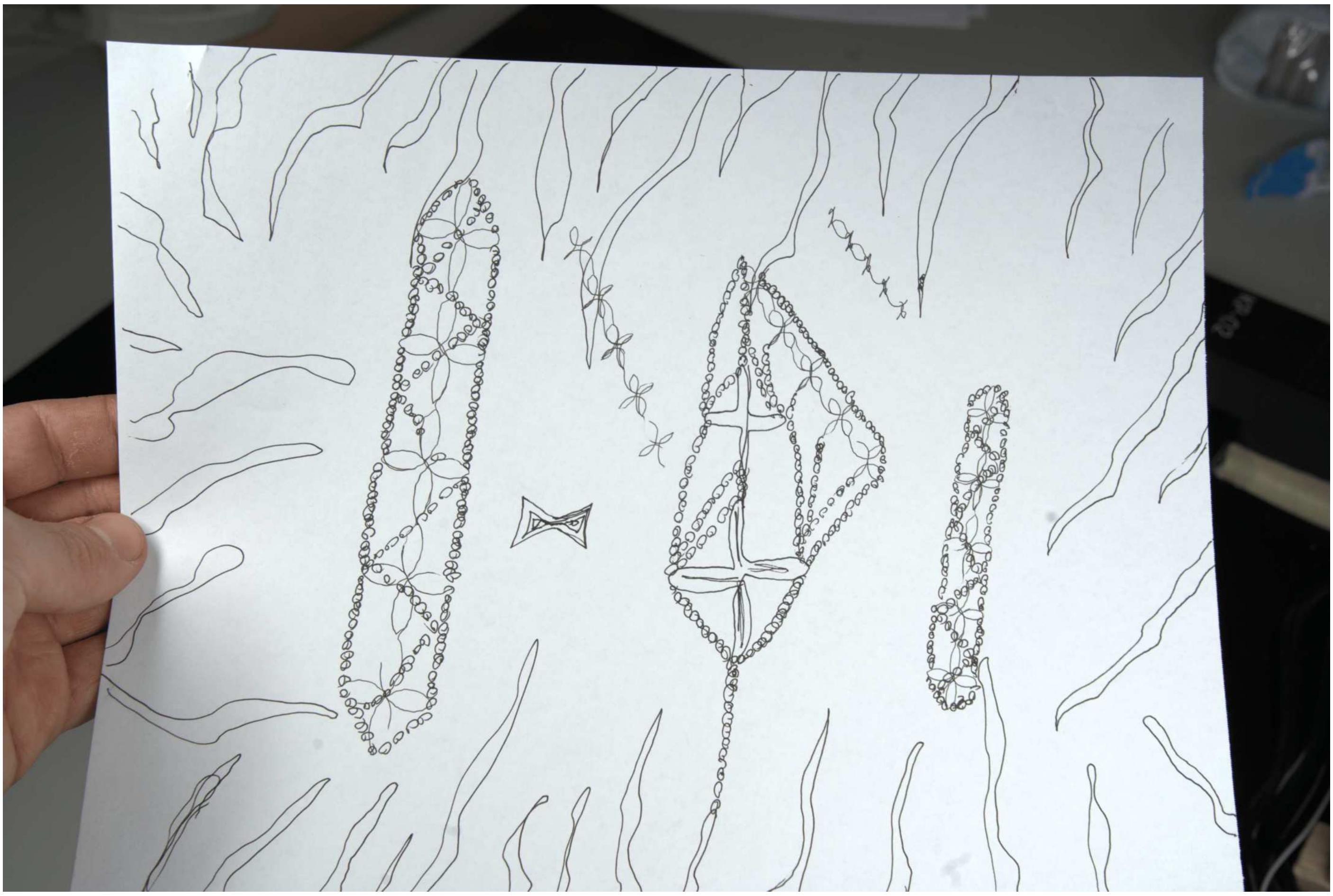
3. **How could the Setup with the Pen Plotter be improved?**

4. **How do you think the Pen Plotters drawing depends on your drawings? How does it work?**

5. **If you have past drawing experience, how do you compare this to other drawing experiences?**

6. **Would you use this system privately?**



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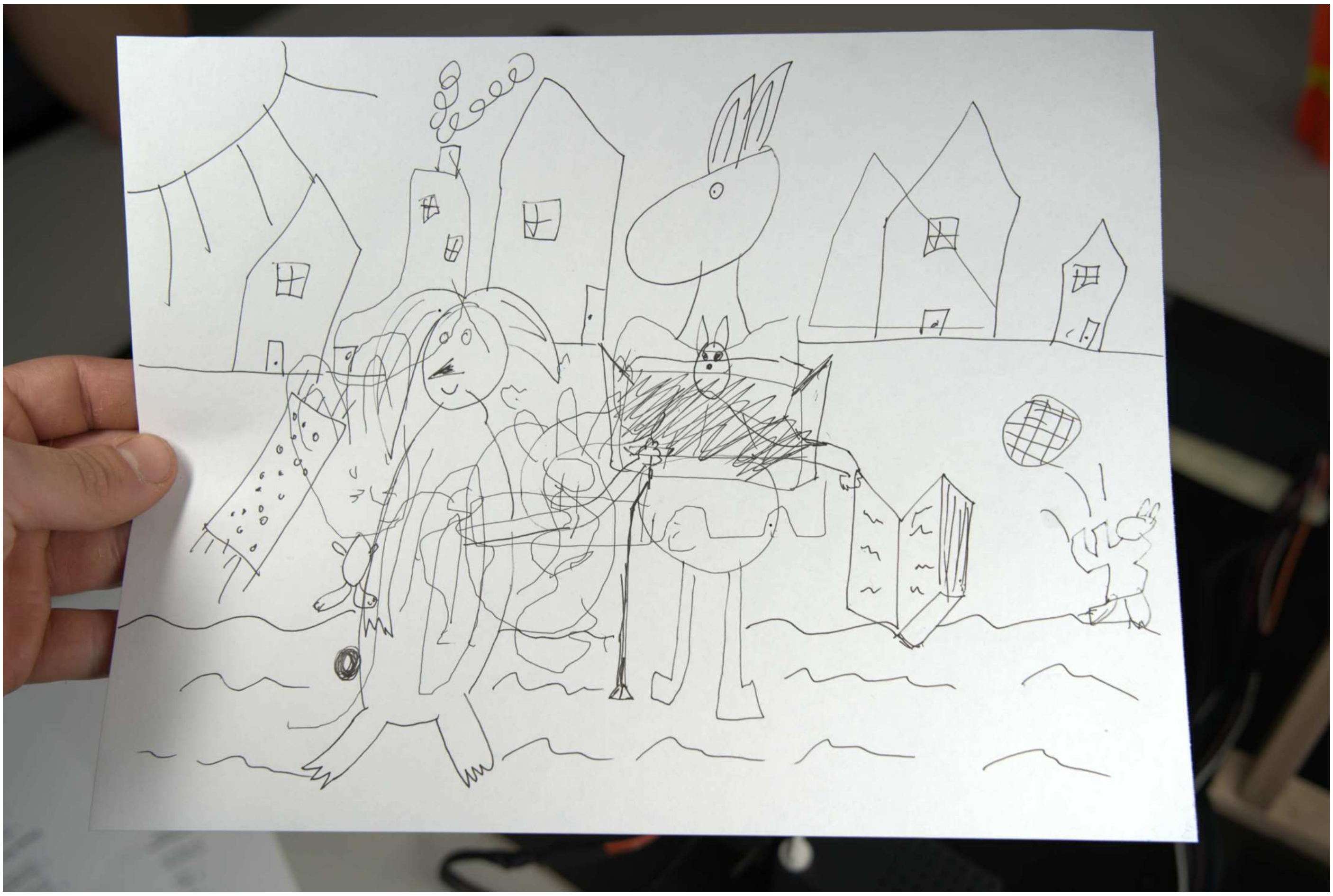

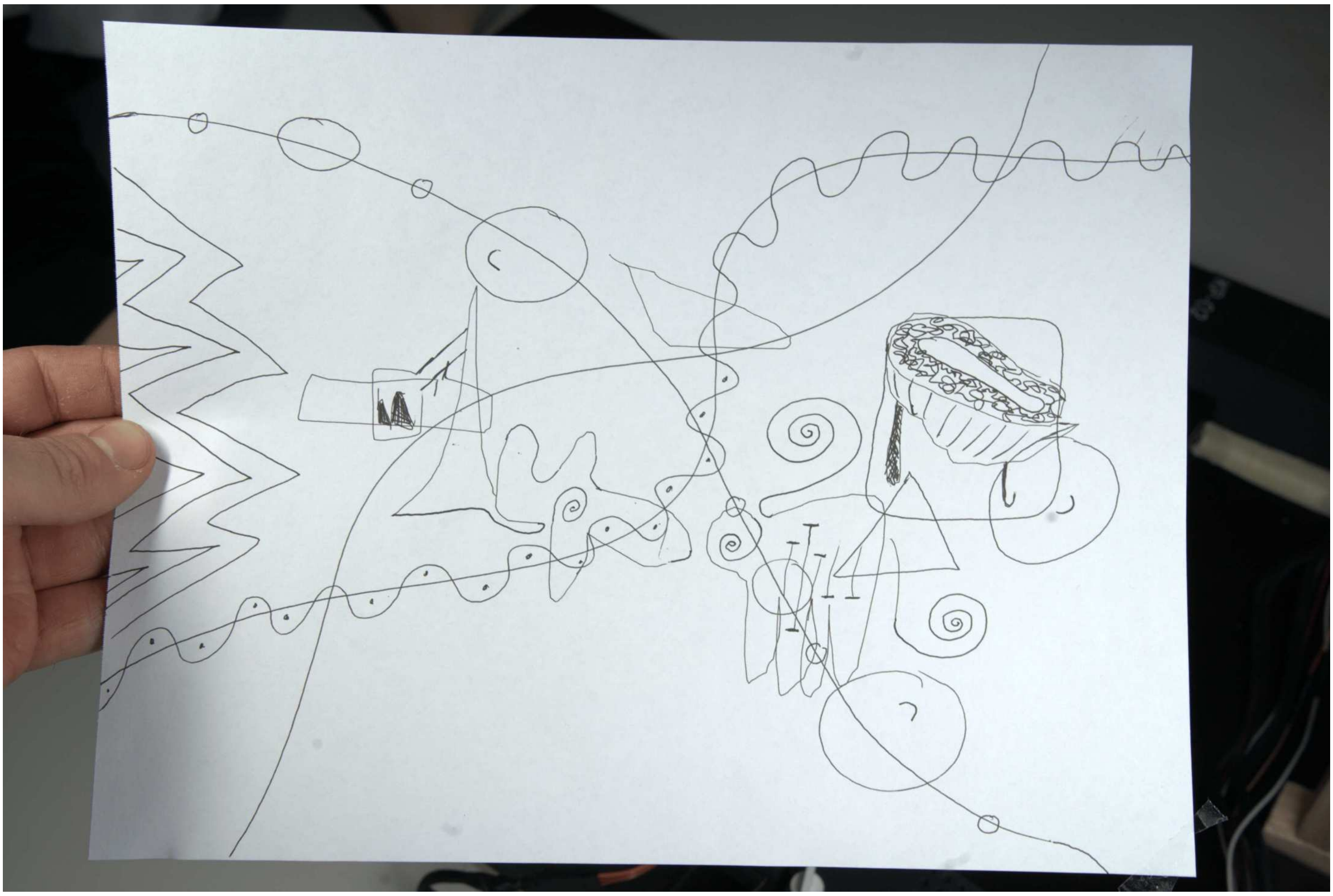

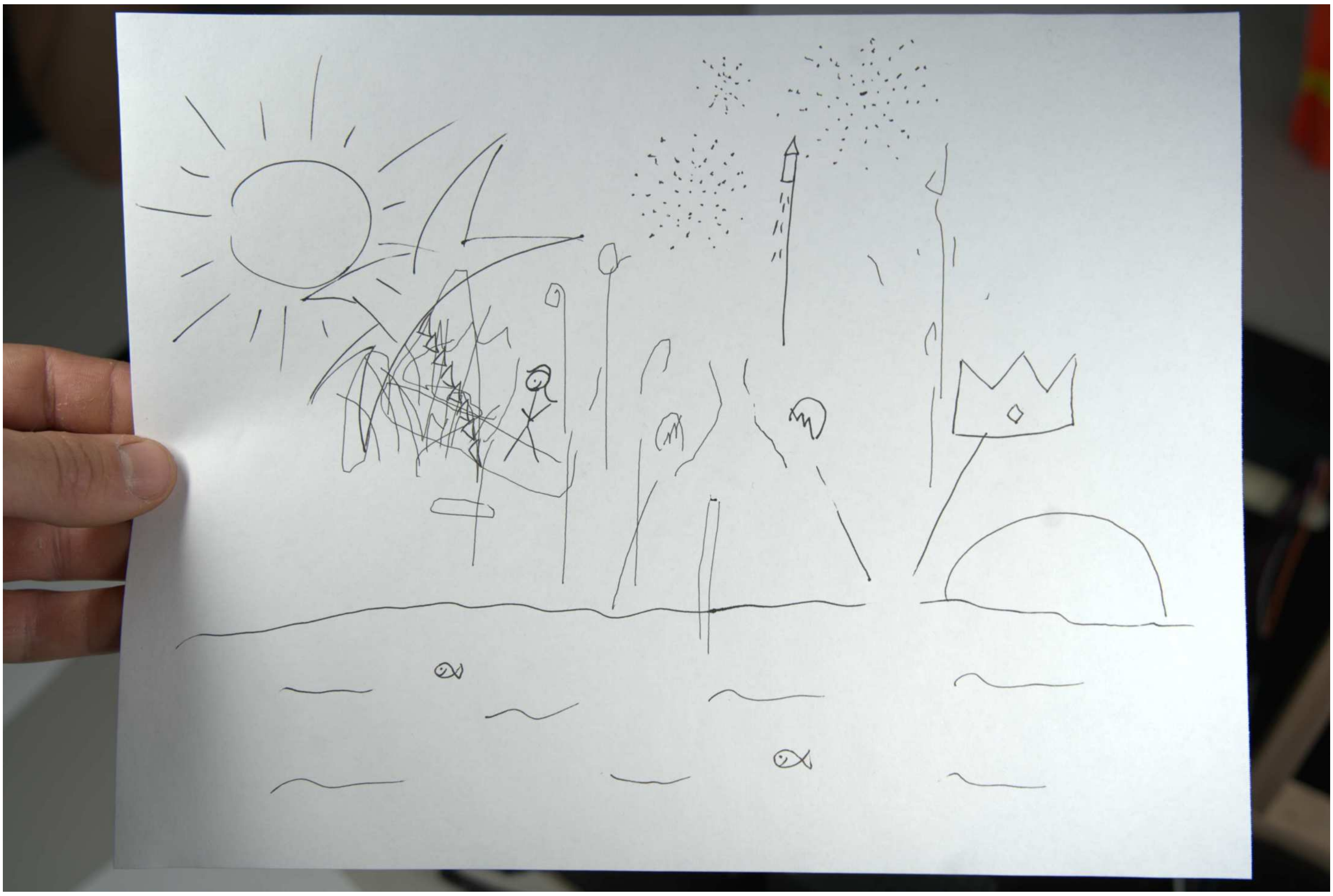


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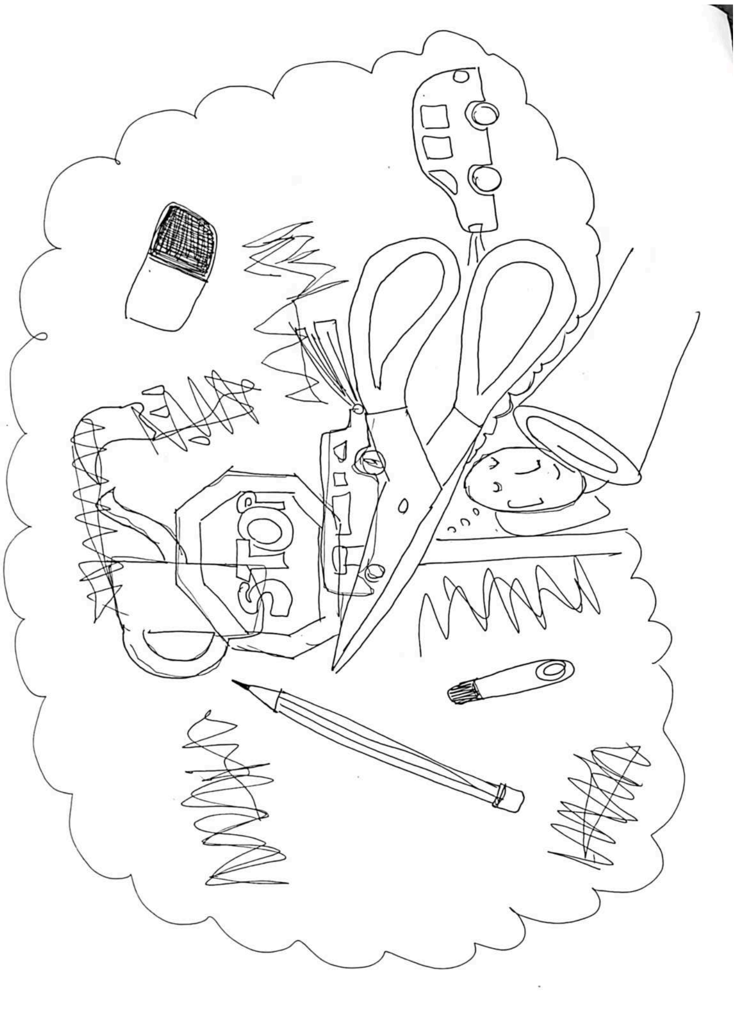
Toothbrush Army
Teeth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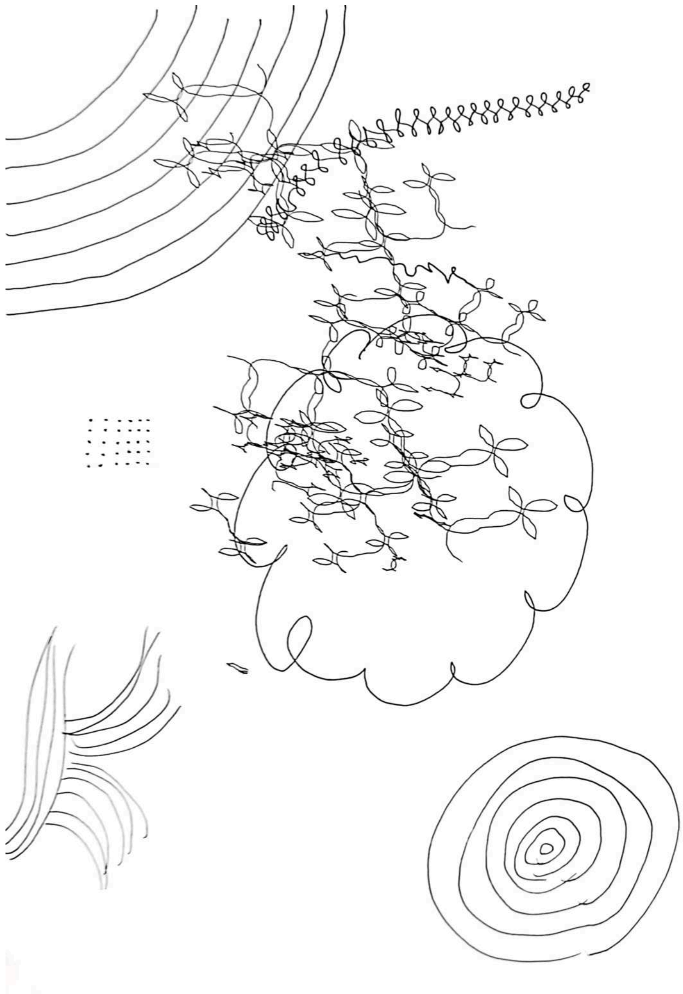

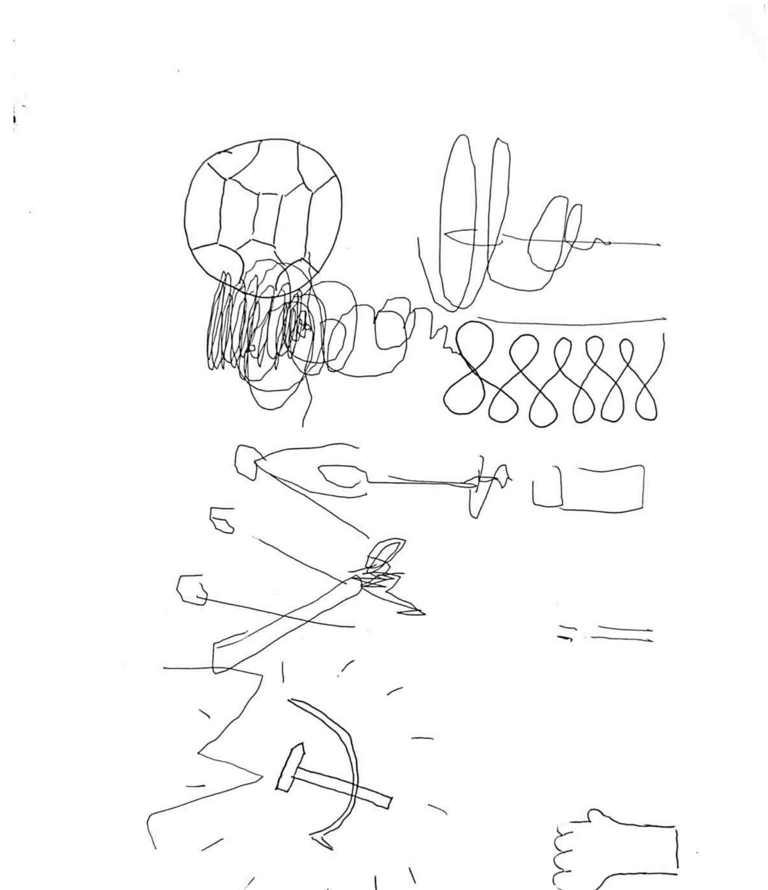

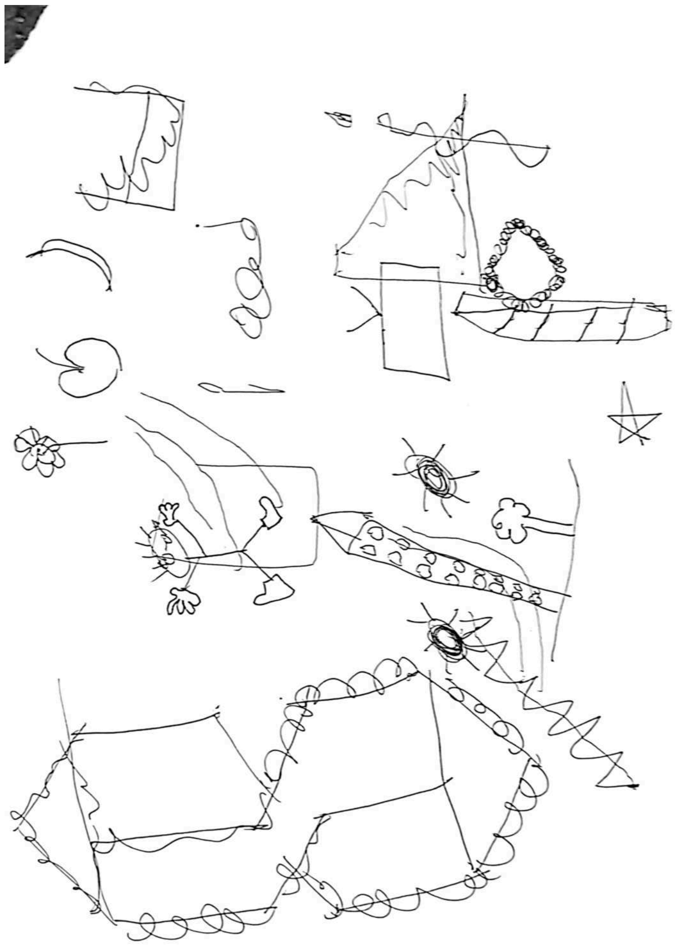

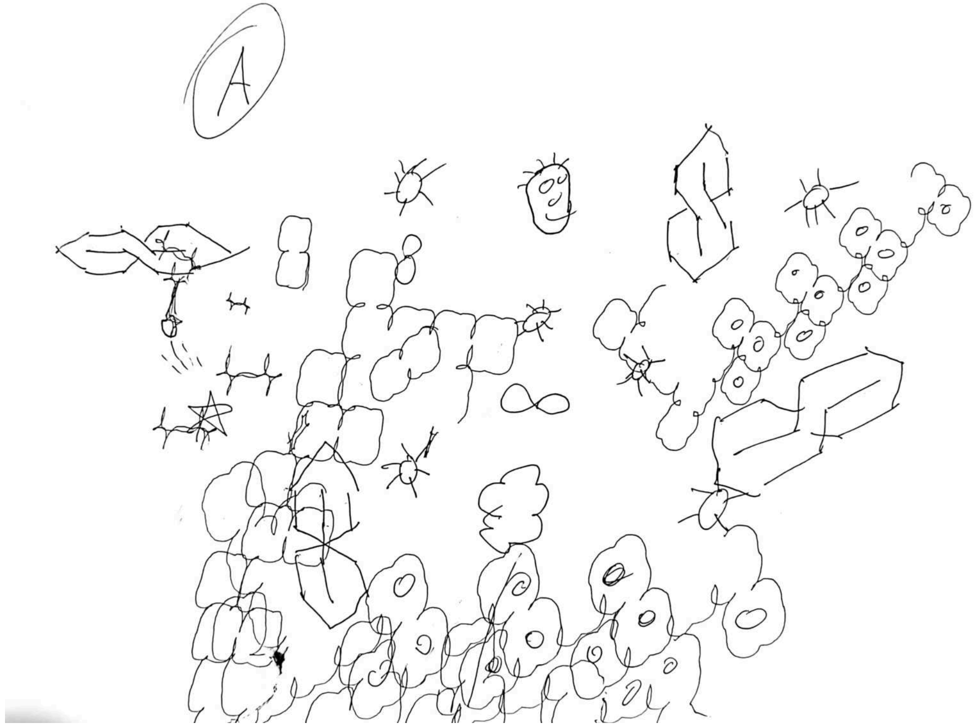
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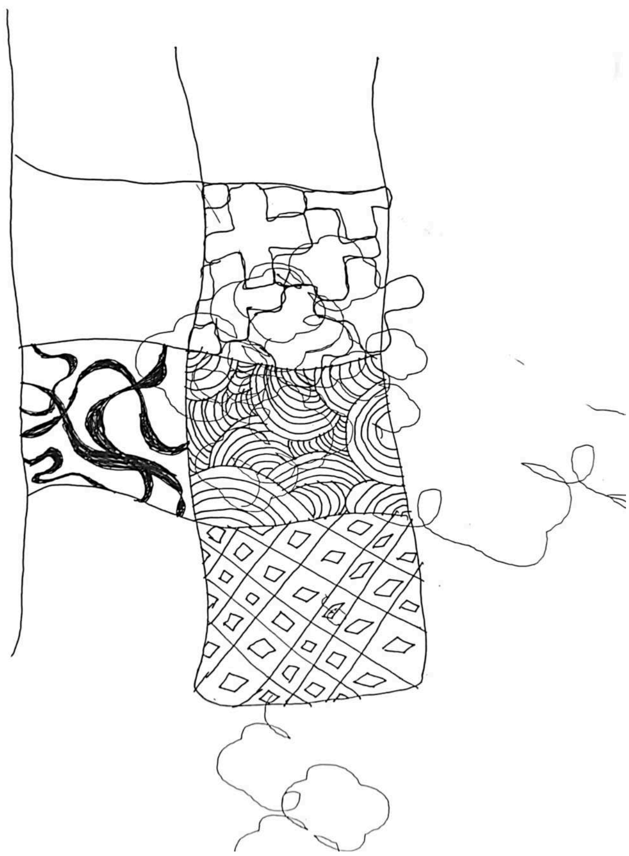
HAPPY B-DAY

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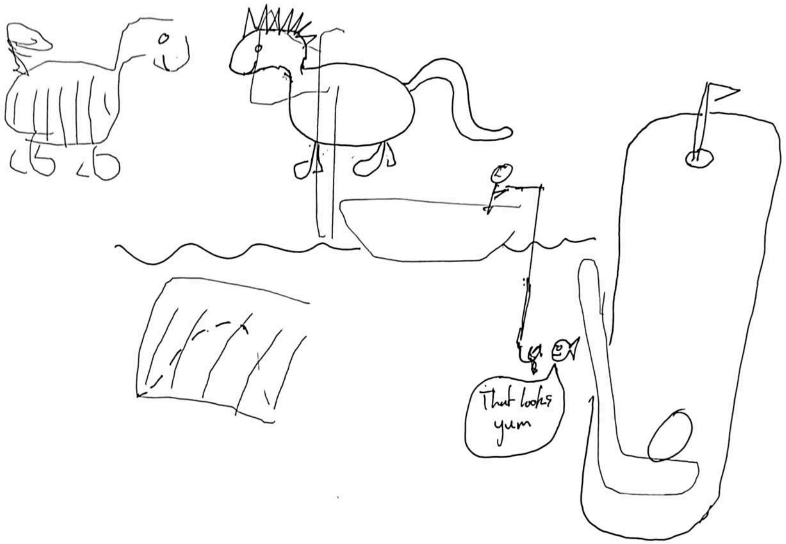
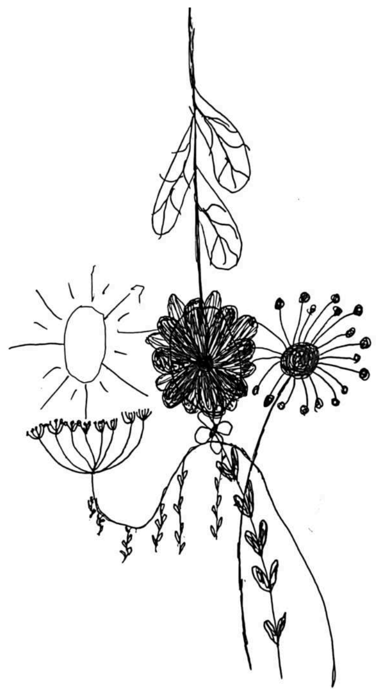
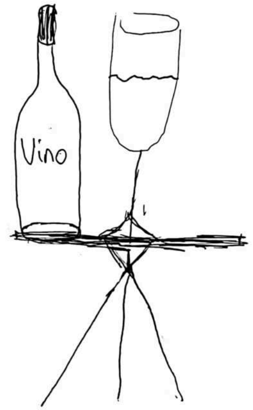

That looks yum

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