MIXED DIMENSIONS: THE INCORPORATION OF TRADITIONAL ARTISTIC ATTRIBUTES WITHIN THE 3D PRINTING PEN

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MIXED DIMENSIONS: THE INCORPORATION OF TRADITIONAL ARTISTIC ATTRIBUTES WITHIN THE 3D PRINTING PEN

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To the late David Stein, My Mother, and My Father

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I would like to thank my Mother, Father, and my friends, without whose guidance, support, and late-night study sessions would not allow me to have achieved so much as well as work so hard. You have made a left a lasting effect onto my life and I hope that I am able to achieve have as much for you all. Thank you.

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SUMMARY

The outstanding impact of three-dimensional printing has provided a variety of outlets for those to create and "express" themselves artistically, as well as drastically affect how we manufacture and develop products. However, hand-held 3D printing products have not had the same luck and as a result draining user's expressive capability.

The purpose of this research and study were aimed at comprehending how artistic traits could lead to a more "expressive" artistic tool and making process. The research describes new dimensions, incorporated painting/sculpting methods along with a pneumatic system to develop both 2- & 3-dimensional works of art. The study with art & design students depicts how the system as well as extraneous additive and subtractive equipment enabled them to have the ability to express themselves through the physical implementations along with modified printing techniques. The result of this study provides insights on how a symbiotic relationship between traditional fine arts (painting and sculpting) and manufacturing techniques like digital fabrication can increase creative diversity and exploration without the negation of the artistic process and expression. Furthermore, insights procured an additional making method within the design space along with a hybrid tool in the arts & craft space.

CHAPTER 1. INTRODUCTION

From powders to paints to plastics, artists as well as makers of all backgrounds have constantly looked for new mediums, technologies, and developments to enhance and explore the boundaries of their work--resulting in an immense amount of diversity. Individual fields like painting, retain microcosms of style and eras populated the landscape in which unique and variegated tools were developed to enable these creators to make, replicate, modify, and express themselves through artistic practices.

1.1 3D Printed Art in Reference to other Art Forms

These art forms focus on expression and communication of meaning and form (Zwirn & Vande Zande, 2017). This concept is closely related with other subjects in the field of art since these forms are connected to the artist or viewer throughout the whole making or experiential process. The creating phase of 3D printing is done through a variety of predetermined values and is usually done separately from the actual making phase. This sort of separation is evocative of interactive and modern technologies, which results in a completely different expressive process than those we seen art forms like sculpting where variables like personal aesthetic, life experiences, and existential concerns inform and direct their work (Mace & Ward, 2002). Since digital fabrication and 3D printed work rely on both the physical making aspect as well as software and digital applications which help users design pieces. The lateral study of digital tools and arts could afford insights in how these art tools promote expression. Expression within digital arts is primarily through simulated individualized experiences, which uses the digital space to alter how one perceives the physical space (Seevinck, 2017). Expression is additionally centered around

the connection between the artist, their artwork, and the viewer. This transitive aspect or process of expression helps relate art forms regarding interactive art to be considered related to other non-technological forms. While interactive art is considered an art form, however there are a couple of technicalities, if interactive is basely considered what would this mean for 3D Printed art.

1.1.1 3D Printing When Referring to Expression.

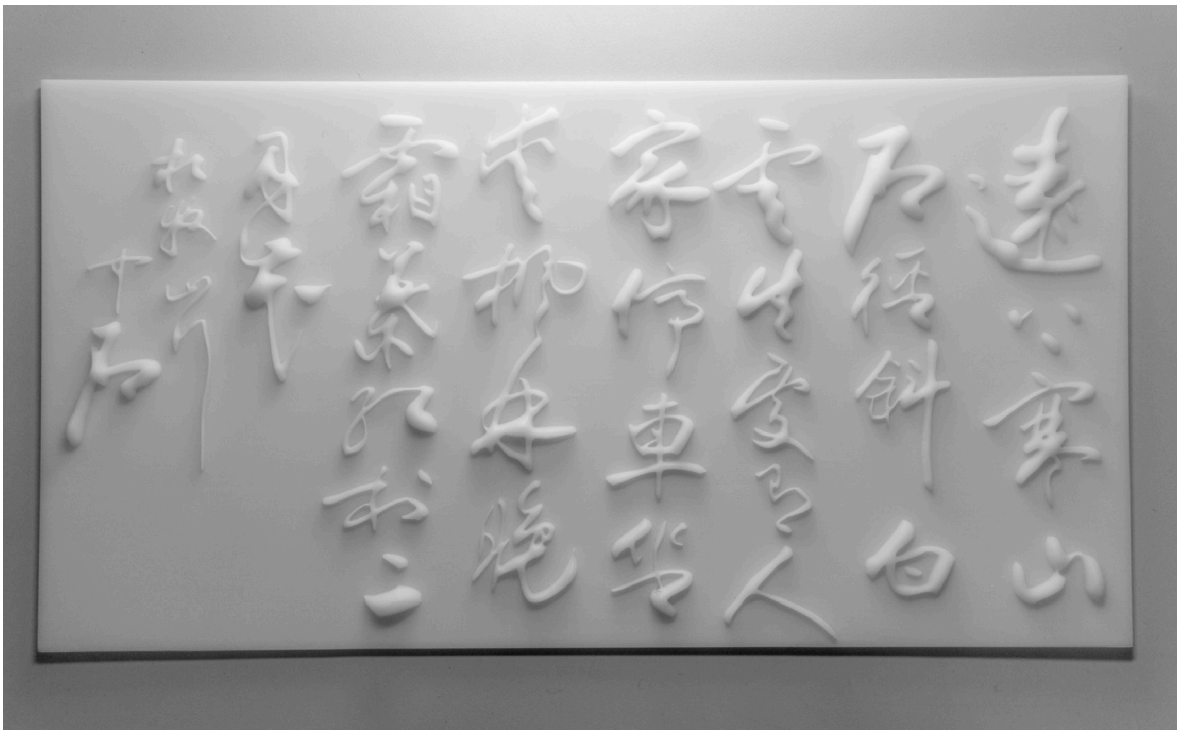

Figure 1- 3D Physical Model (written by calligraphy master Zhangshi Ouyang)

3D printing has taken hold in the areas of design for quite a while. It also appears to have grown in areas such as the arts for decades. While 3D printed work has been around for decades and has allowed for artists to develop unique installations which can be seen in various works like X.Pose (*Xpose*, n.d.). In X. Pose, a wearable garment that turns personalized data points into variables that controls the level of opacity of the garment, the

3D work is quite meaningful and thought provoking using the creator's personal data in every aspect of the piece, from the fabrication to the visual application. The piece lacks initial visual stimuli. Even though it does have an innate interaction of changing levels of opacity and experiential factor its application heavily relies on the data points that is given by the creator, resulting in a personalized yet "common" geometric pattern that is normally seen with a variety of data visualizations. The piece is also lacking a sense of physical connectivity during the making phase which is seen in several 3D models were the software and the mechanical making phase are completely separated (Estadieu et al., 2017). In other works recreated by Yin-Ren Chang the holographic arts we see the same aspects (Chang & Richardson, 2015). Normally, this software are based on mathematical equations and algorithms are considered in Segerman's article DESIGN OF 3D PRINTED MATHEMATICAL ART, where functional model-making and geometric strategies are discussed (Segerman, 2014). However, the main reason 3D expressive work is considered "artificial," is the disconnected relationship between the artist and their work. Which can be seen in a calligraphic poetic artwork above (Figure 1). While the work does provide an intriguing result and diversity within the field it begs to question what work could have been developed if the whole making process would have stayed with the artist. Especially since the integration and use of digital fabrication in areas such as design education has proven to be quite beneficial to k-12 students, resulting in strong communication of ideas, problem solving skills, and learning outcomes (Song, 2020). This hypothetical question began research aimed at how the novel tool, 3Doodler, allows artists to craft along with what this device enables regarding elements of art & expression.

This paper reviews the nature of creating artistic work with 3D print along with digital devices while exploring how customary artistic tools can be introduced to handheld 3D extrusion devices to afford expression in its craft. Historical research was used dive into the relationship between devices and art/artists. Then I conducted a two-part case study which was used to help understand whether initial aspects of artistic tools derived from the historical research are essential and provide newer alternatives to the handheld extrusion techniques. Resulting in a possible framework for developing 3D art tools that could integrated produce a higher expressive ability within the making process.

1.1.2 A Collective Analysis of Traditional Art and Interactive Making

Prior research involved understanding expression and how it could relate to 3D arts was at the forefront. Articles collected on a variety prototypes focusing mostly on affordances that hybrid tools allot users to practice were analyzed via affordance mapping. Factors used to categorize a tool's expressive or explorative capabilities focused mainly on Expression, Agency, and Physical Affordances (Figure 2). Once all products were mapped there was a considerable opportunity space which allowed for 3D printed craft to be fit as a bridging tool between art and manufacturing/Design. A variety of tools eluded interesting facts on exploration and expression of the artists. 3D printers in the terms of art excelled at creating work close to those seen by professionals. Yet the interactions between the making and iterating were not reminiscent of standard arts. The making process relies on the result of just making an object and the limiting factors which are inherently structured by the craft, which inevitably results in constricting of the artistic experience (Martin, 2015). Another insight that was observed through understanding researchers process was that once the work was developed was no longer included. FreeD as well as a variety of augmented hand-

tools in the article *The Wise Chisel* encompasses Intuitive Engagement, Computational Control, and the design process into a developmental tool that bridged a sizable gap when learning a craft (Zoran et al., 2014). The resulting work was of a variety of styles and elucidated human expression. While it did so, these tools did not allow for it to have a natural sense of independence in their combined agency since these are training tool the prompted users and guided them only allowing slight variations on preprogramed equipment. This begs the question on how much agency does a user need to be expressive.

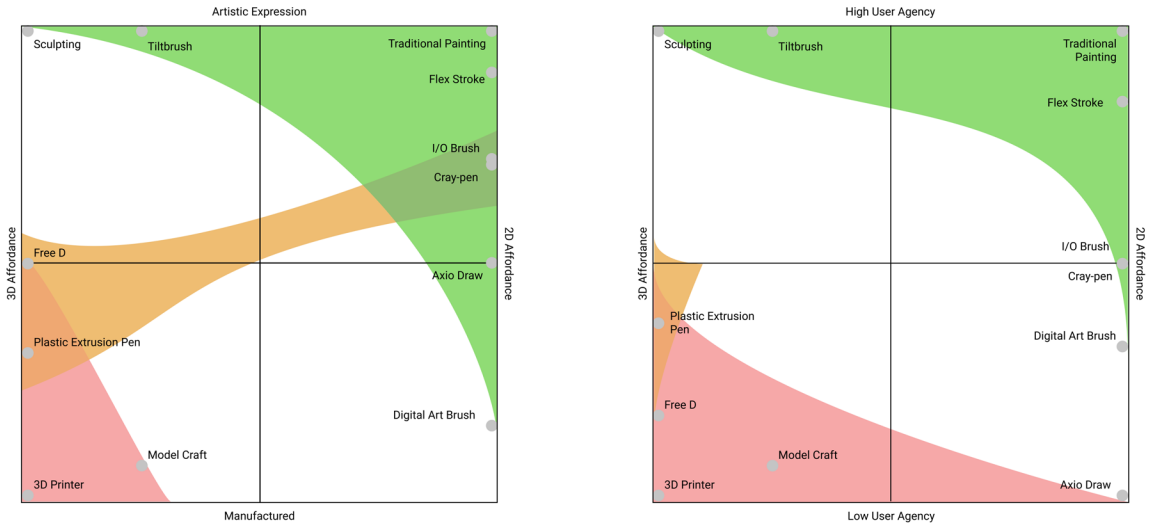

Figure 2- Expression Graph

Since traditional characteristics of art more encompassed the insights above, these being a real experiential connection. Weiming Du and colleagues in *The Analysis of the Interaction between Digital Art and Traditional Art* focuses less on deciding which outcome is more advantageous and more on how digital art could influence along with develop traditional art form (Weiming Du et al., 2010). In this circumstance, roles are being reversed since the lack of interest in Extrusion pen artwork seemed to have plateaued, where many users have reported the device as faulty.

Digital art and design tools were also analyzed as a source of information, especially since digital art or interactive technology has engrained itself so easily in media culture due to a sort of connection and expanse of possible forms of artistic expression (Carlton, 2014). Influences like these are seemingly implausible or at the time not really conceptualized for tangible or digital 3D making process. One study with interactive exhibits using leading technologies, the study's findings revolve around intimacy and interaction rather than just appreciation and application (Fels, 2000). The emphasis that the article implies might be that for a form to take shape and possibly evolve the practitioner might need to gain a deeper connection with the work or the tool that is being used. This ideology was shown in the work in the design study, FlexStroke; In the study users were able to modify the textures of a stylus through granular jamming (Liu & Gu, 2013). While there was no study to judge the devices efficacy and influence on users making experience, another study observed the effects of haptics and digital drawing on the users. Users took a short survey, the results were that most preferred the haptic feedback when drawing and writing (Jeng-sheng Yeh et al., 2002). These findings support that technologies can influence developments in artistic products. Furthermore, the allowance of users to have a choice based on their work and imbue a bit of themselves affords a higher level of making.

My research elucidates three major insights regarding exploration and expression: The first being, artists need to make a more physical connection though either their instruments or their work to achieve proper expressive abilities. When referencing the plastic extrusion pens, which does make physical contact and resemble something of a regular pen, the material does not empower users to make artistic or meaningful work. To strengthen this argument even further material was also observed to be a contentious issue when analyzing

the product reviews. The second, the instrument should borrow from classical arts traits, this should enable experiences relative to the Creative Artistic Process (Mace & Ward, 2002). This should change the style of making from a linear process to a reactive or fluid process. Lastly, the user should feel like they themselves are in control, giving the user agency or a "blank canvas" would allow them to explore different possibilities within their work, resulting in more diverse art. Later research capitalizes on these findings resulting in the development of a physical prototype embodying these paradigms.

1.1.3 Researching Mindful Doodling and How it Relates to Expression.

While physical connectivity aides in the tangible or real making process, the same goes for the mental relationship in making. When analyzing reviews regarding plastic extrusion pens users expressed grief because of the high amount of skill and the inability to manipulate work the way they intended. With such focus on skill and fine attention to detail, this could have led to a deterioration of creativity and confidence that is needed (Rasouli et al., 2016). The two studies reference the difficulty that one might face studying and participating in crafting or making could overtake the creative mindset. Before, questions regarding the addition of technology plus skill level might result in their inability to express themselves through their work. However, it appeared to be more apparent that it might be a mix of affordances that the device enables for the user. Since the tool's ability rather than the user's skill was theorized to be the great filter for exploration, then a deeper dive regarding what makes exploration natural must be as seamless as other related forms. These issues and constrictive interactions would hinder the making process and grind the creative artistic process to a halt. Increasing the mental gymnastics and effort being

expelled. A proper model to influence exploration and expression would be representative of doodling.

CHAPTER 2. IMPLEMENTATION

2.1 Prototyping & Material Development

Previous research discovered that aspects, like physical connections, making techniques, and developmental creative practices like mindful doodling used to create artwork effects how one expresses themselves with a given interactive tool. With this knowledge at the forefront the development of a tool that encompasses characteristics that are relative along with abide by traditional elements of art. Elements of art are of the following: line, shape, color, value, form, texture, and space (Forrest, 1984). While it is apparent that a variety of these elements are based on the skill and physical form, there are a few fundamentals that needs to be selected on the basis on what the material affords.

2.1.1 Material Study

From here an array of mediums were selected to test physical attributes. Physical attributes that were admired were those reminiscent of the PLA Material used by the 3Doodler as well as traditional oil/ water-based inks. To be able to do this, materials would need to be readily available. Requirements that influenced material decisions are that mediums should have a short solidification time that would allow users to build structures. Low heating requirements would be optimal so that material can flow naturally as well as be altered in a timely manner. Furthermore, materials needed to have the ability to iterated on no matter the phase in the making process. Lastly, materials must be related to what users would have experience with as well as what the crafting community has used. From there tests were conducted using common or parent devices. In this case these were hot

glue guns, extrusion pens, and brushes. Once placed a timer was set to measure the average time it would take to solidify which can be seen in Table 2. Shortly after materials would be applied again in layers along with whether materials can show value and texture.

Table 1-Material Study

	Melt/Cure Temp.	Heat/Cure Time	Solidification	Viscosity	Build	Malleable
ABS/PLA	221F	50 Seconds	0 Seconds	Solid	Yes	No
Beeswax	144-150F	2 Minutes	5-10 Min	Low	No	No
Concrete	50F	3-7 Days	-	High	Yes	Yes
Clay	275F	15-30 Minutes	-	High	Yes	Yes
E. Wax	150F	180 Seconds	30 Seconds	Low	No	Yes
Ink	N/A	N/A	N/A	Low	No	No
Hot Glue	380F	2.5 Minutes	~60 Seconds	Medium	Yes	Yes
P. Wax	150F	10 Minutes	~5 Minutes	Low	No	No
Resin	75F	24 Hours	-	Low	No	No
S. Wax	150F	30-60 Seconds	65 Seconds	Low	Yes	Yes

As shown above in Table 2, I selected a diverse set of materials that are commonly used in craft and fabrication activities. Ink and ABS/PLA were originally used as a control for other materials to compare to. Variables that were deemed as important were malleability,

build, and viscosity. Malleability centers around what I considered the three S's (scratching, stretching, and smearing). Scratching is embedding texture negatively or positively with a knife or nib. Stretching is whether the material can be stretched while cooling and hold it while cooling. Lastly, smearing is based on whether the material can be spread. If materials were not able to perform these tasks or failed other's that could make it unique then they were not considered.

Resin, concrete, and clay were appealing options since they are mediums that are commonly used in 3D printing. Yet, they were not selected for further development and study because these materials were not readily available. Furthermore, aspects such as cure times were not considered practical for Hobbyists and the study. Moving towards other options, sealing wax was projected to be the perfect material for the study later down the line, its liquification and solidification times were close to instant. Which would allow the material to be molded and manipulated. However, its liquid form was not as viscous and would blob or run making it nearly impossible to build upon it. On low temperatures the material acted more as intended but textures were more akin to rubber, this would not allow users to cut or manipulate the material unless additional devices or heads would melt the wax. This was tested with the heated nib of the hot glue gun and allowed for clean stencil work along with the mending of material.

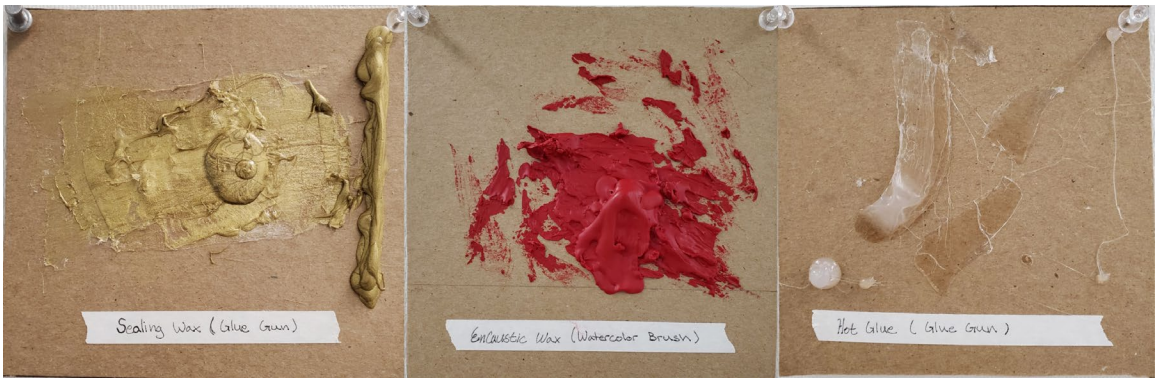

Figure 3-Physical Material Study (Left to right Sealing Wax, Encaustic Wax, and Hot Glue)

From the Figure 3, hot glue was also promising since the material's characteristics were evocative to clay. However, hot glue's malleability while in its dried state was not easy but possible. The encaustic wax or painters wax acted like the sealing wax when it came to flow (which was a problem), though it took less time to solidify as well as the felt stronger. Re-heating was not a constant issue since it did not require having to a constant switch between two temperatures. On top of that it was easier to apply texture due to the structure and which is a bonus in comparison to the remaining materials.

Since many of the top materials, has negatives that balanced out the positives my next thought was to mix these materials with one another. From here, I had learned that while promising the sealing was did not take to the hot glue well, making a consistency that was close to silly puddy. When mixing hot glue and encaustic wax the result was a less viscous mix that still did not provide enough structure to stop it from flowing off the back. The Use of borax was added to the mix to make a thicker solution like seen in Oobleck. This drastically changed the flow to that of Elmer's Glue, additionally it also affected the dry time of the wax. The effect of the mix resulted in a solution that flowed with minimal effort,

dried reasonable quick, was able to be smeared. During the study, the material was iterated on to achieve the right consistency to be extruded once the mix was measured properly the "Borwax" mix was tested a final time. This final test used food syringe to replicate an extruder nib, was heated, and material was displaced onto a chip board panel. The outcome of these results was optimal and can be seen in Figure 4 , the material was able to be extruded, produce varied amount of material, controlled line weight, and was able to produce vertical spires without additional support. These findings and newly discovered abilities were used to guide each iteration of the prototype/system.

Figure 4- Borwax Extrusion Syringe Test Results focusing mainly on vertical and horizontal making.

2.1.2 System

MixD (Figure 3) consists of three main components, two of these possessed instances within itself. The whole system consisted of an air tank, a SparkFun Arduino Red board, a

Solder Dispenser, and a MixD Pen. The system worked as follows, the air tank would supply dry air to the A 982A 110V Glue Dispenser Machine Solder Paste Glue & Dropper this would regulate air flow into the Mixed Pen. The pen was made up of a plastic mouth connected to the copper pipe by wings. The shaft of the pen is comprised of copper with and Adafruit heating element fixed to it. A fastener connects the lower body to the shaft, and the head is made of 3-5 sets of aluminum nibs. The Arduino which regulated temperature was powered externally as well as the heating element.

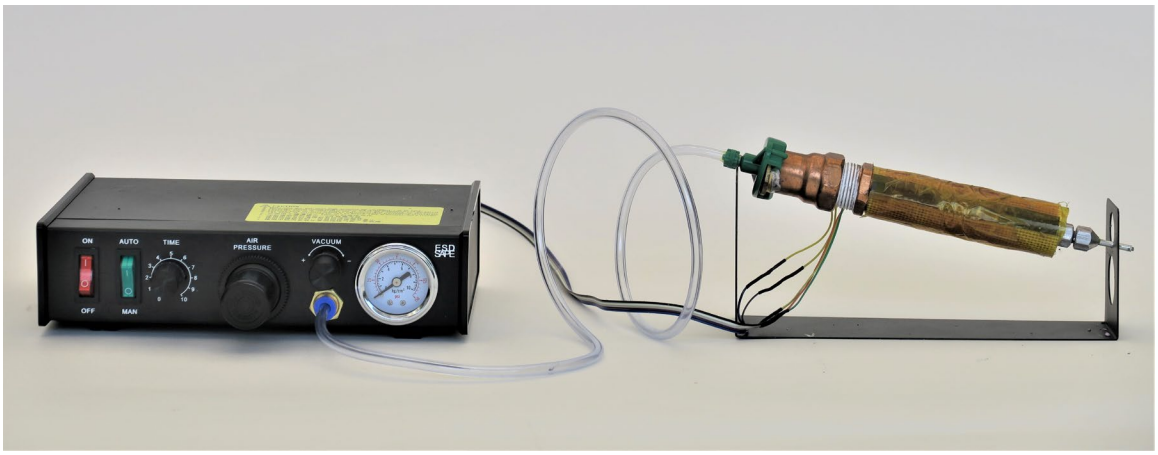

Figure 5- MixD System

2.1.2.1 Design Decisions

Devices of this nature commonly used automated mechanical attributes to displace material out of the head of the device. While this was considered, 3Doodler was referenced, discovering that and mechanical parts hindered control of the device. Furthermore, the final system used air as a driver to replace plungers along with manual cranking mechanisms that are commonly found in caulk guns. This allowed for the pen and its canister to be used multiple times without having to procure extra during a making or crafting session. The

body was made of copper to easily conduct heat, as well as keep material from cooling while being extruded. The fasteners were fixed to the piping to better connect the mouth to the body, this area was later sealed with Teflon tape to stop air from escaping. The mouth which connected to the back end of the device was now the main entry way for reloading material since it was easily removable. Wings were added to create an airtight seal as well.

Though the heating element was external, the conceptual goal focused on affixing a hot glue-like heating element to the base of the device however, after mocking up the early model of the prototype it was ascertained that the part could not allow enough current through. A heating pad was used with a multimeter to determine the appropriate temperature and voltage necessary to have the pen heat efficiently, this temperature was at around 110 degrees Fahrenheit. This revelation was important since the prior prototypes used pre-set heating devices, while this did melt the material it later would burn it and cause discomfort for users. Since the heat output mainly controlled the handling of the material. I was advised to borrow from similar devices heating concepts such as hot glue guns since many of them have dual temperature regulations. This was done through placing a temperature sensor through a couple of layers of silicone as well as having a Mofset read the temperature and voltage allowing me to program when the device should heat up or turn off.

Other than the managing when and how much material is deposited designs were centered on the nibs or heads that the pen would be able to have. The notion of multiple nibs was done to help test whether agency affects user's expression when making. Multiple nibs were created so that users could have as much choice as possible as well as test

whether any heated nibs could be used to add texture or additional flair to any developed artwork. Giving users both an additive process and a subtractive process if they choose to.

Figure 6- MixD nibs (left most nibs were produced while the right most were built for glue guns).

2.1.3 Case Study

The study that was conducted is primarily focused on theory that the acquisition and incorporation of traditional artistic methodologies as well as physical traits could influence a "natural" form of expression and exploration when hobbyists practice art. The study centered around Phenomenological – Qualitative Research and consisted of the experiences and perspectives of hobbyists. These methods were chosen since expression along with imagination is not an easy topic or word to comprehend. Plus, these subjects are reliant on variables like users, materials, processes, and products. Casual Creators or hobbyists were sectioned to students only to the college of design rather than included all students from Georgia Institute of Technology. Participants that were considered revolved

around those who have practiced artistic mediums (Sculpting, Pottery, Painting, etc.) for 2+ plus years yet do not follow through to a professional career. Participants were also accepted if they have experience with 3D printing as well as worked with in a 3Doodler. Initially a total of 10 students were considered however due to Covid 19 and the timing of the semester 5 students was the final number of recruited participants.

From here a lesson plan was devised for participants to be introduced to the tool, during this time the participants were shown a brief demonstration of basic tool functions, once the demonstrations were completed participants were given the tool and asked to perform several tasks. These tasks were as follows:

- Extrude a droplet of material onto the board.
- Remove the piece and place it back inside the device.
- Extrude a layer of material across the board.
    - Thin Nib
    - Thick Nib
    - Flat Head Nib
- Extrude for 4 layers on top of each other, build a wall like structure.
- Build a vertical structure (this could be a line in the Z axis)
- Make a 3Dimensional Shape (cylinder, Square, etc.)
- Depending on what you have made please add details (like inlaid line, circles, scratches etc.).

Participants followed these short number of tasks then questioned on their experiences with 3D printing devices as well as MixD. Once this section concluded, participants gained the opportunity to engage in a session of play. In this session participants would create and develop their own work. This was without instruction as to not direct or sway any ideas or processes that could possibly change any results. However, participants were asked during the making/play phase to understand experience and thought process. This session concluded with an interview session that was evocative of the Creative Support Index or grading system (Frich et al., 2019). This index is based on focused on having participants

asked a set of Yes or No questions regarding Collaboration, Enjoyment, Exploration, Expression, Immersion, and Results Worth Effort. These questions are later scored, these scores determine how supportive a tool is to a user's creativity. The way this system will be used in my study is based on the first section of what was discussed prior. I plan on pairing down these questions as well as forming new ones. When questions are asked, I would try and facilitate further explanation. This will be done to inform later prototype iterations as well as display elements of expression and art.

CHAPTER 3. DISCUSSION

3.1 Overall Impressions

This paper and case study question whether the making experience of 3D printing pens can be altered and promote expression through Artistic characteristics. These characteristics revolved mainly around material-physical attributes along with developmental ones. These subjects and tools were graded through Agency, Expressiveness, Process, and Quality/Satisfaction to ensure that the user's expressive abilities were met.

Overall, participants were either intrigued or excited by the interactions that MixD provided them. During the task section of the study smiles, laughter, and intense concentration were displayed once participants started performing tasks. When asked to switch from task to task and not allowing participants to experiment participants were visually upset. With many participants stating some play on the following:

"It feels a lot like playing with a hot glue gun but with a lot more control over the settings... I want to poke and extrude and play with it in my hands maybe yeah I just really like breaking and playing with it." - Participant 3

Users insist it is like other making and artistry tools like the hot glue gun, sewing machine, and potter's wheel. On several occasions, users tended to break their work and either draw with it like a normal crayon or completely reduce it to crumbs when asked why users stated: "(p1) I like the pearl-like look, it's interesting because the exterior texture

does not match it." When transitioning to the to play session participants appeared to be very confident with their making ability.

Users accidentally started to compare MixD with traditional 3D printing in addition to extrusion pens. When discussing their making experience users appear to fixate on how the materials, enjoyment/expression, and the making techniques that relate to it. One user stated "It was frustrating...I remember it had a really small extrusion nib and that it only let out plastic... but um...you had to be super precise with what you were drawing. At that point, we were trying to make rings but the stuff we extruded was so brittle that it was kind of useless." In comparison to the MixD device-making experience, the user stated, "It's like not my plan but I don't feel frustrated… this one you can see that (when making) the material is changing by itself it feels like you and the material are doing something together." This commentary elucidates an interesting occurrence that the material presents on the user's expression and experience.

3.2 Role of Expectation & Materials on Expression

Users noticed the resemblance of other artistic mediums almost instantly, which evoked a sense of curiosity to initiate their open-ended play. When asked about their process on making with MixD, Participant 5 stated "I think my focus is definitely on the material, like I kind of forgot about the rest of this going on (referring to the system) …again I think speed is my concern, how I move the pen is how the material stretches and moves.". This statement depicts how the interactions were based on one another depending on how the material was dispensed from the nozzle. Informing the user on how they should orient themselves around the page or the material. I believe this was the case since users spent

less time focusing on how to operate the material and device allowing them to perform tasks quickly. The reason for this thinking is that the artistic experience is based on reactivity and intuition rather than deep thought and developmental planning.

Participants reported that the reaction of the material was interesting almost describing it as having its personality. The way users interacted with its personality was more of a study with, participants would extrude material and observe the results that were displayed informing participants and basing new iterations on the previous interaction. The medium almost seemed to influence the aspect of mindful doodling, especially since some participants had stated they had no plans or idea what they wanted to make. If they did have a plan that failed. There were some minor instances where failure was apparent in work. Participants were asked how they felt about this failure users stating "… Um there is no expectation that you would be able to create something that like could be used... it's just different." (P3). When comparing the expectations of a typical 3d printing pen user had an unflattering mindset towards the material. Participants described that there was a disconnect from what they were making that "the filament was a lot a smaller... I think like point 9 pencil lead, it was neat for the first time use but was not practical for making art unless you had the patience to build something with it... that seemed to be the consensus of my class..." (P4) MixD's material altered 3D printing expectation on the art-making front. And seemingly developed a reactive making process like that of open-ended play and mindful doodling.

3.2.1 Problems & Limitations of Material

Expressiveness and Quality of the system were measured by whether a participant could apply their emotions and detail to their work. However, users defined Expressiveness as the ability to build the object which they envisioned by their imagination. This finding altered our study question regarding expression to focus on creativity and the results of their imagination rather than finite details. The ability to build what the user envisions based on creativity is a success showing that the tool does both facilitate expression as enhance the making experience. While being a success it might be merit in analyzing the material failures. Some build failures that participants pointed out were developing layered lines or 3D shapes like a 3D printer would. These issues were seen during the task phase and early play session. These could be attributed to the borax fluid cooling time. Here, the material would take longer than expected to cool making build quality suffer and result in leaning/collapsing structures. Another explanation is that this problem is because of growing pains and first-time use. Especially since a variety of students stated that they should wait longer in between layers before starting the next part. Users later tried pausing in between layers and shapes and were able to develop work with little to no difficulty. Also, the instance that users could cool the material themselves by blowing or any other method was not possible due to covid restrictions. Could the pneumatic system in this case be used to help build structure? And gain control making it more individualized rather than collaborative. Additionally, the device system itself retained heat quite well which would liquify material. Though there was a feature in place to monitor heat, this being a Mofset and Temperature sensor to control voltage, it appeared to but ineffective at points. A possible way to fix this issue might require different components to monitor the amount of voltage flushed into the system like a shift regulator.

3.3 Agency & Enjoyment on Expression

Users also described having little control over the material and felt like there were too many aspects to control to get a replicable result. They asked for the aspects of the tool to be pair down to just the basics like color and nib size. When observing them I think users were subconsciously doing these actions. They would stick to their favorite nibs and prefer the use of manual settings believing that if they had switched to the automatic timed dispensing setting that it would ruin the creative process and tarnish their expression. One participant did decide to switch to automatic and was able to create a maze-like structure (this was probably a success for them because the maze was very basic in form). However, knowing this it might be advantageous to limit the actions one might have rather than allowing them to engage with an expansive assortment of functions. In addition to this, it could be beneficial to incorporate an offloading system that can be relied on whenever a given task mirrors a mental model.

However, the exorbitant number of variables that they were able to control did not appear to influence their ability to create and express themselves through their work, I hypothesize that this might be because their interaction was seen as playful and once again doodle-like. When asked about this insight Participant 5 stated "I think it is okay, it's a little like finger painting. Now at least I am just trying to figure it out. There is no like 'oh this is a high art material, so you have to make something very refined like it meant to be played with or experimented with.'" While this mindset of making low art was perceived by most participants, they were still able to develop interesting forms shown above. In conclusion, the excitement from seeing a different result illustrated, a sense of unrestricted play, and reduction of cognitive output highlight possibilities to subjects that had not

initially been considered or thought to be applicable. If the interactions were too easily replicable or did not allow variety in results. I believe their agency, lack of engagement, and expectations would constrict their abilities.

3.3.1 Problems & Limitations found in Agency.

When referring to Agency questions were directed or centred around choice and their ability to control the device or system. In the study user's choices ranged from when or how much material is displaced to how much air pressure will be used. While they were given a wide variety of items to choose from there was one aspect that users believed that they did and did not want to have control over like air pressure. Participants' choices were altered or seemingly tailored due to the randomness or reactivity of the material this was seen with participant 4 during the task phase where a varied line was supposed to be created and instead something reminiscent of spider webbing was dispensed from the nozzle. This can also be seen in the play phase where drizzling was done to build up structures rather than the typical layering of lines seen in 3d making. The exponential thermal conduction done by the pipe body of MixD was hypothesized as the issues that produced these effects like the spider webbing in tandem with the amount of air pressure that was injected into the device. A possible way to fix this relates back to the programming done for temperature monitoring were and external Arduino and program would have dominion over the amount of pressure based on the heat and volume of material inside of the chassis.

While they relatively gained more control over the device and material users felt that the material was collaborating with them. Yet, I could see how the material not reacting as fully expected and creating a new building method could become cumbersome and make

users feel like they are being stripped of their independence. The idea of this becoming a feature is interesting, but I would be interested if this would be a common occurrence in other user groups like professionals. With the information that I have now, I could see this new building feature and restriction of one natural making choice being fixed by discussing with users what choices allows them to build along with what added on to their cognitive load. Participants 1-5 were all observed during both play and task phases not really caring to switch nibs when asked to. This instance was theorized that they either had too much choice during the making phase or because they favored one nib over the other. This idea feature is not seen as a limitation since users were able to execute their own set of choices rather than be forced into a nib by the system. However, while this may be the case users did wish for more decorative variety in both areas of subtraction as well as addition. The way I see to enhance this feature of more choices is through taking a collective survey of which nibs are preferred or allowing a focus group develop nib types for making overall. This would allow more time to be spent developing nibs that are more decorative and subtractive.

3.4 Discovery of Techniques

When starting the study users seemed to have a random or spontaneous way of making. Initially, this was thought that users were adjusting to the tool and by the end of the task phase, users would inevitably change. Using the device like an ordinary pen tool, this was not the case and users appeared to already develop their insights and making methods without instruction or direction. Approximately 4-5 methods were observed, and some were also used together to develop 2.5 D to 3D pieces of art.

3.4.1 Additive Technique 1: "Sketch" & Make

As discussed before participants took a particular liking to the material texture and consistency to the point that users would pick and destroy random and previous work. This can be seen in Figure 7 below, once this was done a user would select a broken piece and begin to draw or sketch. When watched further the participant would appear to mindfully doodle and slow format possible ways that they can make their ideas come to life. This drawing method was noteworthy because this was not a personalized occurrence where about half of the participants would begin to draw out ideas absent-mindedly while waiting to start another task or at the beginning of their play session. The other participants had another way of mimicking this process instead of breaking pieces off they placed the nib's face directly on the face of the board and extruded. The result of this is a completely flat profile that produced a more visible outline for designs and are to be made and layered on this can also be seen in Figure 7 below.

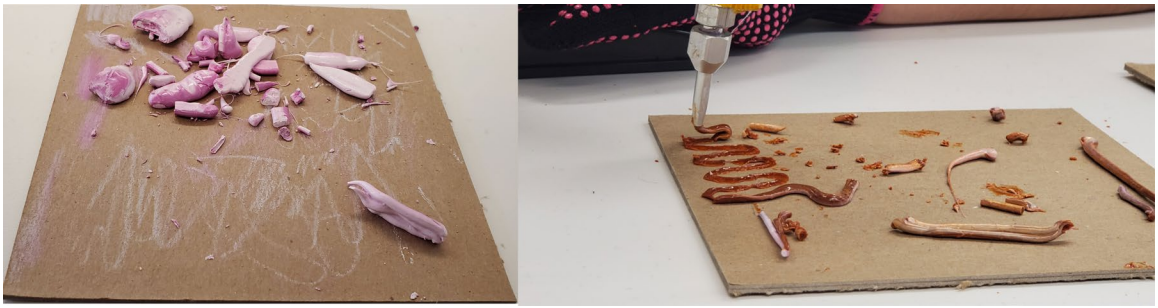

Figure 7- Example of sketching and drawing prior to layering up.

3.4.2 Additive Technique 2: Drizzling & Dripping

Some participants decided to use the reactivity of the material as a building and detailing method. For example, Participant 2, who favored the thicker nib would hold the device in

the air to seemingly gain more control of the device resulting in a base layer that slightly represented the form that they were going for. When wanting to detail specific areas the user would get closer and lay droplets or wiry lines to pronounce specific areas. While this was an odd occurrence it does supposedly change the techniques that users normally used when making with a 3D Doodler. When comparing the two, the making process of the Plastic Extrusion pen did not fit the mental model or "the 3D printing moment" that the users originally wanted. If users were able to achieve this process it was only in the upwards direction and would not allow them to draw effortlessly in the air. However, with deeper discussion users did not prefer a "tighter" or supportive additive process of creating tight swirls to build-up structure and deeming it unpractical for making and detailing. When asked about the drizzling interaction users did not mind this since they were able to stop the flow of the wax and twist or maneuver the piece and start up again. Once again, this process was not always successful and many only applied it as a problem-solving method for reaching hard places or building thick strong structures. This can be shown in the Figure 8 below where the participant was testing ways to build a tree full of leaves and a truck this method was also done when another participant was doodling and wanted to create a spire in the middle of their piece. In addition to this method participants produced dripping towers during their task sessions, at first this was to get rid of scrap wax that was coating the nib. When the user was asked if they believed they could make an object more complex they tried to make an archway with this dripping and stringy method. Though they said it was not a success they still seemed impressed with the outcome. Then in the play session participant 5 had used their time trying to implement this scrapping method to produce a tree or mushroom-like structure shown in Figure 8. This observation is noteworthy because

it displays a new additive-making method with this material as well as shows proficiency in developing work with such little time.

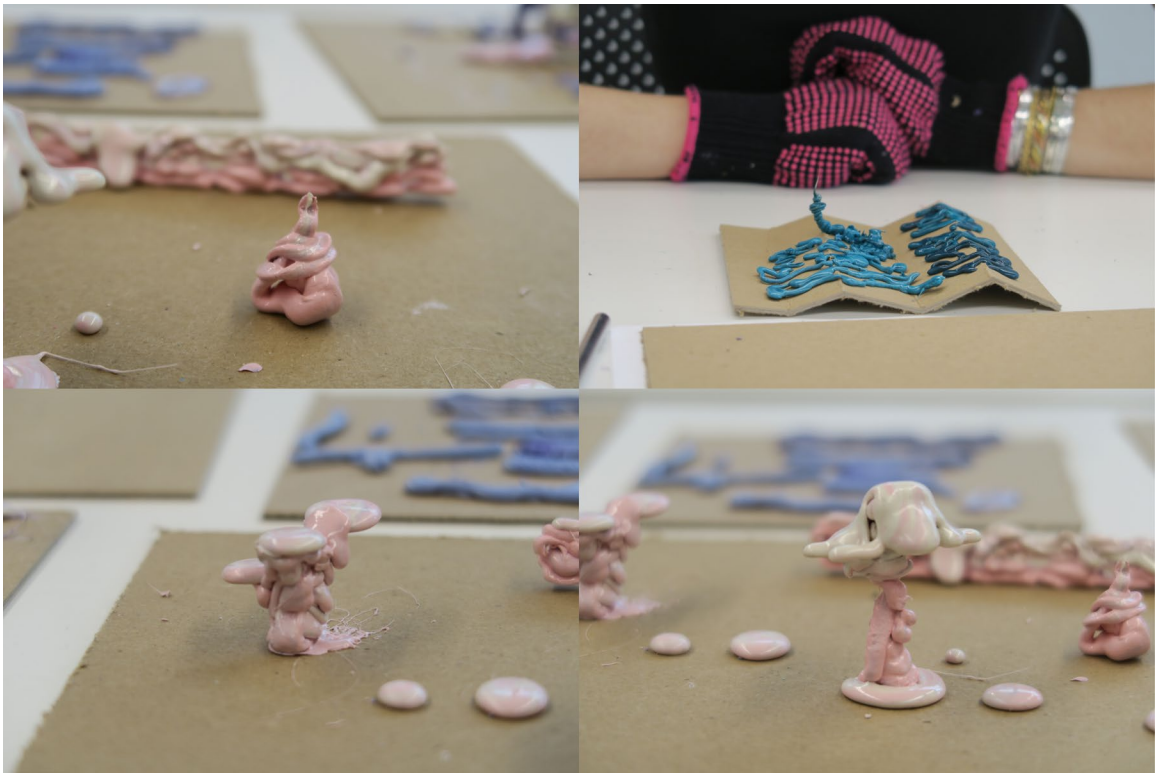

Figure 8-Iterations of the Drizzling Techniques

3.4.3 Additive Technique 3: Gluing

Gluing was seen in the previous section pictures. In this method users placed molten material on the board or other wax parts that were previously built. The user would then place the intended piece(s) into the molten wax and let it set and form a strong bond. They would add additional molten pieces to the prior structures resulting in a complete 3D piece of work. Users found this method easier to use when building and allowing them to create the next piece stress free. The method had given users freedom to make work that felt as if it had a higher level of skill without taxing the user. Resulting in complex structures shown

above and below (Figure 9). These pieces did not rely on additional support material or linear thinking seen in 3D printing or in the 3Doodler pen. Lastly gluing gave users another method to incorporate into their work if structures were not able to be built through layering.

Figure 9- The Snail above was made by combining all three defined methods of building (Sketch/Making, Drizzling, and Gluing)

3.4.4 Subtractive Technique: Carving, Imprinting, & Brushing

And when asked about having multiple nibs, participants were open to these interactions. Despite the open arms, users seemingly selected a favorite and would normally switch to induce a set reaction. This was not the case when using subtractive methods on the extrusion nibs especially when detailing. While some participants thought that the ability to make using the nibs was interesting and later developed work articulating:

"…the ability to use multiple nibs is really cool. It's subtractive like I have been pressing the circles into the blobs and with different nibs, I can make different shapes to press." Initially, one would believe that the additive nib carving method shown in Figure 10 was the optimal process for providing detail and texture. While participant 4 was the one who made the detail, they later voiced their issues with the process stating, "It's really hard to see what I am doing, it clutters the hole… yeah I have to clean it.".

Figure 10- Detail creating this tentacle was created by pressing the extrusion nib into the wax.

In fact, a few participants had not particularly liked this feature, and asked for tools specifically for melting, moving, and carving. Furthermore, one user while creating detail had asked and used an X-acto blade to implement more detail. During the second phase of the user study, Participant 3 indicated their difficulty with trying to implement detail with this nib and process by uttering "It melts slightly different in some parts I hit a snag … I kind of believe that I could make detailed work out of this, but I don't really have a lot of control about where the displaced material is going." When asked if there was a way to give users more control in detailing, the response was "If there was a way that I can scoop

the material rather than a melt and push something like a linocut tool, if I had something like that, I think it would be easier."

As a result, I had developed additional nib heads that were brush like as well as one that replicates a fine tip stencil tool found in sculpting. When this was tested users were interested in the brush tip noticing that it did provide a light form of texture and almost a mixing/smearing of colors. Unfortunately, due to a lack of time I was unable to create a variety of nibs that match the same purposes used in these tools. Furthermore, the fine tip nib was not used seemingly due to a lack of interest and with more time there would be a focus testing a variety of subtractive detailing nibs with participants.

3.5 Conclusion

In this paper MixD, a pneumatic pen tool that allows users to extrude Borwax and make 3D printed Work with art hobbyists. The device and material enabled artists to engage in making techniques that were relative to the Creative Artistic process along with facilitate expression, which were originally not included in modern printing and extruding practices. Collectively, exemplifying possible ways to use new materials extrude said materials, and make. The user study examines the effect of my device on hobbyists making experience. Suggesting that the system developed helped users focus on the activity of play along with the interaction between the intended artwork and themselves. Allowing for users to experiment with less additional effort. In addition to this, the device allowed users to focus less on the quality of their work which unintentionally helped with cognitive load.

For future study, it would be advantageous to develop a wide variety of texture or building based tools for users to explore more advanced forms of making. It would also be beneficial to rework the components of the system especially around the hand-held

instrument, by improving the housing, which would better safety parameters, as well as decreasing the size of the device would better aide users in handling the tool.

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