Surface Metrology Interactive Impasto Art Museum Exhibit

An Interactive Qualifying Project Submitted to the faculty of WORCESTER POLYTECHNIC INSTITUTE in partial fulfilment of the requirements for the degree of Bachelor of Science

Hailey Fink
Worcester Polytechnic Institute
December 2020

Report Submitted to: Professor Christopher Brown

i. ABSTRACT

Education institutions have been working diligently to include more, science, technology, engineering, and Mathematics (STEM) geared curriculum into their school systems. However, this leaves out the important category of art, which would transform the ever-popular STEM into STEAM. This project aims to show children that art and science can work hand-in-hand. Using a Sensofar microscope, measurements of impasto artwork will be taken and a method detailing how to print these measurements will be determined. These Three-Dimensional prints will be used to design a touchable exhibit with interactive features that will engage children to learn about the study of Surface Metrology and how it can be applied to the impasto art style. This will provide them a fun and memorable example of science and art coming together in one museum exhibit.

ii. ACKNOWLEDGEMENTS

A very big thank you to...

Dr. Chris Brown
for being the Advisor on this project providing direction and guidance,

Connor Cummings
for training and assistance on the Sensofar microscope in the WPI Laboratory,

Adam Murrison
for 3D modeling, data format conversions, and 3D printing work,

and 2Over2Design
for assistance sharpening the exhibit graphics.

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1 INTRODUCTION

1.1 Objective

The objective of this project is to design an art museum exhibit with the goal of teaching children about surface metrology and confocal microscopy using STEAM. This exhibit will explain the technology utilizing interactive art elements throughout the exhibit's design.

1.2 Rationale

There are many areas of engineering that young children are not usually exposed to and are unfamiliar with. Surface Metrology is one of these fields. If an art exhibit can be created that would engage children while also exposing them to this engineering field, they will enjoy discovering its application and perhaps become interested in this or other scientific endeavors as they progress through their education.

1.2.1 Kids Learn Better Through Play

When children go on fieldtrips, they are always excited to get out of the classroom, but they often dread the thought of ruining their fun with learning. That's why science centers, zoos and aquariums are such great trip destinations. They offer fun interactive experiences while also exposing children to real life science. A Reddit.com survey, performed in conjunction with this paper (Appendix A), surveyed over 80 science and engineering students at Worcester Polytechnic Institute (WPI) and revealed that only 3.6% of this sample found trips to art museums to be their favorite, while 48.8% preferred science center outings. Their favorite locations have fun learning environments that encourage play, touch and discovery. “Play is an integral part of development. Through play, children develop their capacities in creativity, problem-solving, logic, social knowledge, communication, self-regulation, cognitive processing, and social development” (Henderson & Atencio 2007). Due to the fragile nature of the subject matter, art museums don't commonly have these kinds of environments to keep young students interested. From the WPI survey, it can also be observed that the respondents, that believed art museums were not a popular favorite amongst young children, had a consensus that art museums were meant for adults and the more cultured, instead of the general population. Their responses included “The art in art museums is almost never made by kids. In my opinion, it also presents itself as "superior" in some way due to adults having more worldly experience” and “Depends on what art museum, but most are stuck up and snobby.” The goal of this art exhibit is to educate through art while engaging children with interactives providing them a hands-on environment to explore and learn.

1.2.2 Enhancing STEM with STEAM

It is imperative to start teaching children that art and science are not exclusive characteristics. It is necessary to show children that art and science can, and do, coexist in the same environments. The old stigma that science and art skills are exclusive, holds back the children that doubt their math and science abilities because they've been taught that engineering is all numbers and formulas and not creative and imaginative. Breaking down these stereotypes could usher in a new wave of engineers that never knew they were capable of solving engineering challenges. “STEAM education in schools provides students with the opportunity to learn creatively, using 21st-century skills such as problem-solving. These general capabilities are crucial to growing a future-ready workforce that understands the potential of “what if” when solving problems that occur in real life” (The Conversation 2018). Cultivating these intersections between Science, Technology, Engineering, Arts, and Mathematics (STEAM) is necessary to facilitate a new generation of interdisciplinary innovators with creative minds to shape our future.

1.2.3 Spreading Awareness of Surface Metrology

Surface metrology is an important field of science and engineering concerning the precise, representative characterization of surface topography, also known as texture or finish. It involves the measurement of a surface’s microscale and sub-microscale features. Surface topography has a critical influence on the mechanical, thermal, optical and electrical properties of materials used to make components, parts, and products (De James et al. 2019). Surface Metrology is used for many different applications, but most notably, quality assurance. Quality assurance is needed to ensure that sensitive equipment, like circuit boards, are dependable and meet design specifications. Surface metrology research covers a large array of topics including but not limited to finding the best ways to limit friction in engines and pistons to create better efficiency, analyzing how water adheres to a surface which can be applied to create more water resistant surfaces, analysis of corrosion and wear over time, and even the study of ski edges in order to determine what methods are best for sharpening skis. While surface metrology plays an important role in many aspects of mechanical engineering design and quality assurance, it is not a well-known field of study to those outside of the engineering arena.

1.3 State-of-the-Art

1.3.1 Recreating Art with 3D Printing (Surface Metrology and Artwork)

Studying art with surface metrology is not a new concept. In 2013, Tim Zaman, while a PHD researcher at Delft University of Technology, developed a new hybrid imaging method to scan paintings with enough accuracy to make convincing reproductions. For his MSc thesis he developed a super high resolution, large-format 3D scanner, especially suited to 3D-scan paintings, and he focused on paintings by Rembrandt and Van Gogh. The data he collected was sent to be 3D printed by High Resolution Océ 3D Fine Art Reproductions. Because the chosen paintings were in the Impasto Art style, they accentuated the highlights and created shadows that emphasize the form of the painting when illuminated with light. This is especially the case of late Rembrandt and Van Gogh paintings (Zaman 2013). “In order to capture this topography convincingly, we needed to capture it in a very high resolution, which is already a problem for most 3D scanners.

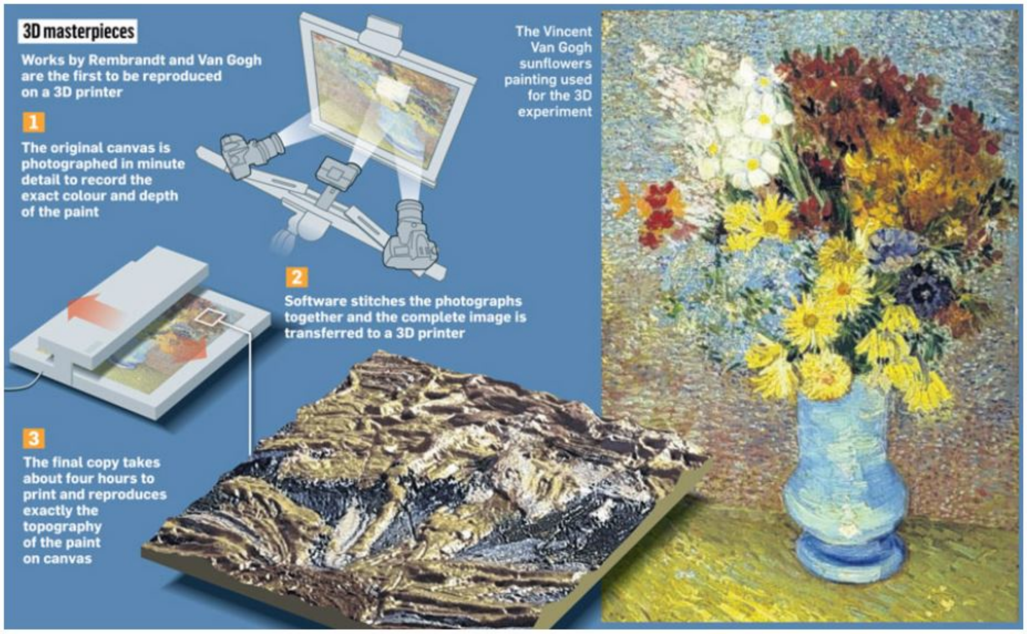


Figure 1-1 Zaman Experimentation

Furthermore, the topography of the paint is very small compared to the size of the canvas and we want to capture color at the same time as we capture depth " (Zaman). Figure 1-1 details his research process and shows one of his reproductions.

1.3.2 Interactive Exhibits (Museums and Education)

From the survey in Appendix A we can see in Figure 1-2 that science centers are a common favorite amongst respondents. This is because these museums are filled to the brim with interactives that keep students engaged.

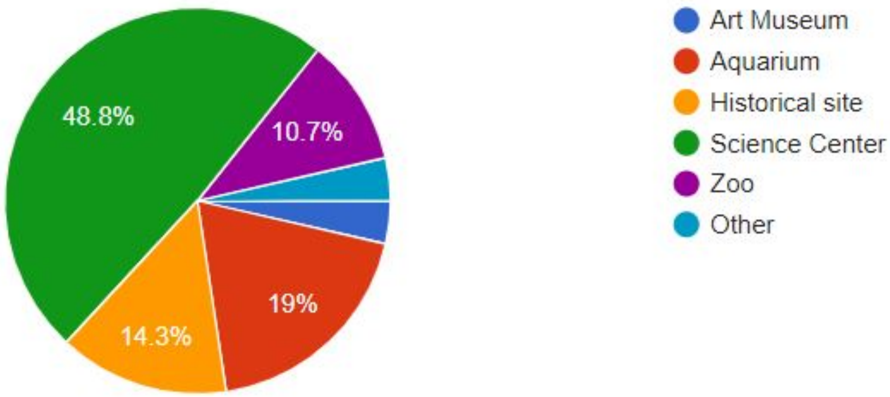


Figure 1-2 WPI Survey - Favorite Educational Field Trip Results

Some of the most popular museums are designed with interaction as their main mission. For example, the 'Please Touch Museum' (PTM) in Philadelphia, Pennsylvania is full of interactive and hands-on exhibits for children to immerse themselves in. (Fig 1-3 & 1-4)

Figure 1-3 Please Touch Museum Interactive

Figure 1-4 Please Touch Museum Water Interactive

The mission of the PTM is to enrich the lives of children by creating learning opportunities through play, laying the foundation for a lifetime of Hands-On Learning and cultural awareness. (Visit Philadelphia 2019)

There are also great examples of art museums taking on the initiative to make visits more engaging for kids.

The Walters Art Museum in Baltimore is a classic art museum that has carved out a niche for children with interactive carts, interactive quilts, and sketch pads (Figure 1-5). On weekends, groups of children read stories and then tour the museum to view related artworks.

Figure 1-5 The Walters Art Museum Interactives

After which, they can head to the museum’s Family Art Center (seen in Figure 1-6), a dedicated area used for involving children in the art process. Here, the children can create artworks integrating the stories they listened to and the museum's classic art they viewed.

Figure 1-6 The Walters Art Museum Family Art Center

The Worcester Art Museum (WAM) is also taking children into account when developing exhibits. Marnie Weir, Director of Education and Experience at WAM explained that they have incorporated multiple engaging elements throughout the museum that cater to children. Some of their activities and exhibits are described in Table 1-1.

Activity	Descriptions
Scavenger Hunts	Families love to use scavenger hunts as they travel through the galleries. Families search or items in the list while enjoying the museum's contents
Medieval Gallery Interactives	These include a helmet you can try on, a sword you can lift, stone-carving tools and materials you can touch, games and trivia you can play on an iPad, books and other reference materials you can read, and more.

Art Carts,	Portable stations throughout the museum in which visitors can draw, play games, and make art inspired by pieces in their collection.
Monet's Waterloo Bridge: Vision & Process Exhibit	Incorporated technological interactives that highlighted Monet's creative process through imaging and material analysis
MEOW!	Which included an interactive installation featuring live cats
The Art & Storytelling of Ed Emberley	This included a stylized reproduction of the artist's drawing and light table from his home studio, where visitors of all ages could try their hand at his techniques, and a specially-designed reading area

Table 1-1 Worcester Art Museum Past and Present Interactive Exhibits

When Interactives are implemented in art museums, they create a more engaging and memorable experience for young visitors. Educating children in this fun manner helps them to gain and retain the knowledge presented.

1.3.3 Incorporating Art with STEM to Develop STEAM

STEAM is championed by many as a way to improve on the concept of STEM education. The Rhode Island School of Design (RISD) calls for adding more art in the national STEM agenda because it feels that STEAM can help develop a comprehensive educational model that will better prepare future generations to compete in the 21st century innovation economy. (Marland 2013)

"STEAM" represents STEM plus the arts – humanities, language arts, dance, drama, music, visual arts, design and new media. The main difference between STEM and STEAM is STEM explicitly focuses on scientific concepts. STEAM investigates the same concepts, but does this through inquiry and problem-based learning methods used in the creative process. STEAM is not a new concept. People such as Leonardo Da Vinci have shown us the importance of combining science and art to make discoveries" (The Conversation 2018).

1.4 Approach

While the aforementioned predecessors have done great work with their individual topics, this exhibit will be designed with a novel approach of combining components from all of these fields of study. Zaman has taken the first steps to make accurate art reproductions with 3D printing, but was not interested in expanding on his research nor applying it to primary and secondary education. "However, I was not interested in any exploitation of this project, I moved on after I did the tech" (Zaman 2013). The Please Touch Museum, in Pennsylvania, has dominated learning through play, but has not been so straightforward with a push for STEM learning. The Walters Art Gallery has incorporated art with interactives but has not linked them with scientific exploration.

This project will look to make a more homogenous application incorporating surface metrology technology, interactive exhibits and the ideals of STEAM. To complete this project, an exhibit will be mapped out and designed, surface metrology technology will be used to capture topography of art, and those rendering will be used to make prototypes for interactives that will be featured in a Surface Metrology Impasto Art Exhibit.

2 EXHIBIT DESIGN

2.1 Comparison Board

The comparison board will be an interactive display that will show visitors the detail and texture that makes up a painting. Once the painting has been created, (refer to section 3.4) three areas will be measured and 3D printed at a larger scale. A poster of the original artwork will be created to match the new larger scale of the 3D printed blocks. The respective locations of the three measured areas will be highlighted. The three-dimensional blocks will be placed on top of their respective areas as the touchable component. This will give guests the ability to touch and feel what the texture of the painting would be, without the worry of damaging the painting itself.

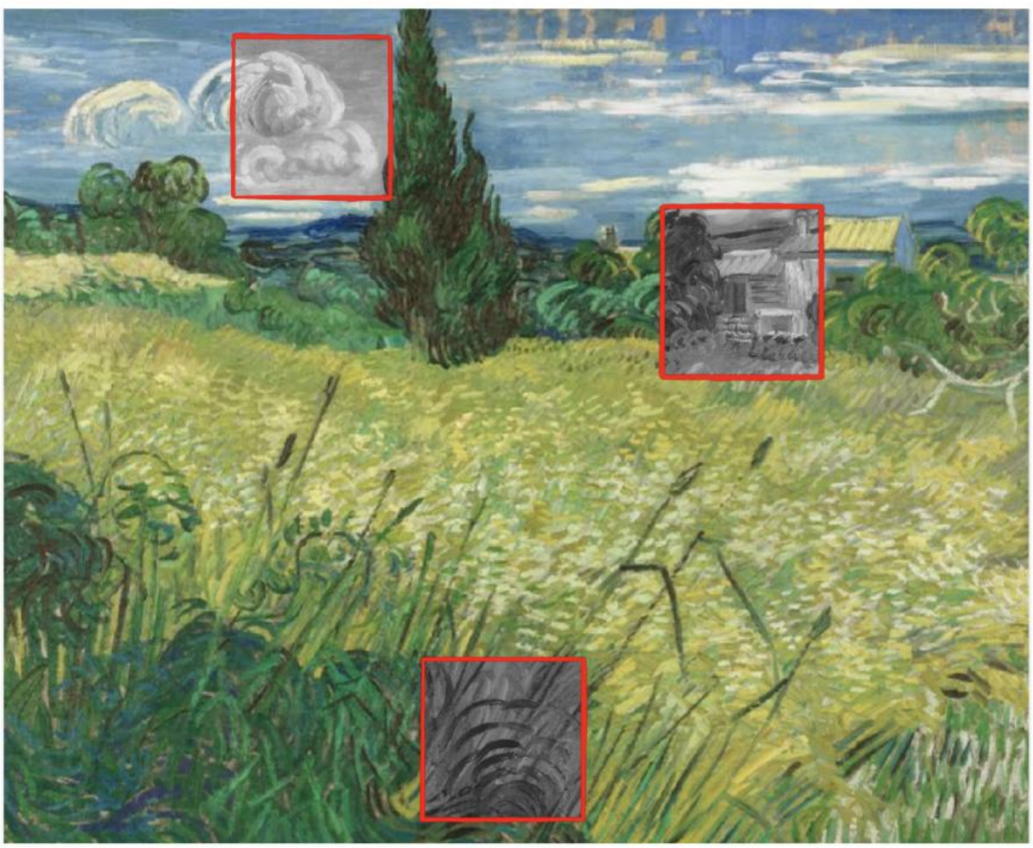


Figure 2-1 Comparison Board Prototype

2.2 Three-Dimensional Print Explanation

The 3D Print Explanation Interactive, modeled in figure 2-2, will be the display that is placed directly adjacent to the Comparison Board. It will have the painting at its original size and the original 3D prints of the prototypes produced from this project, seen in section x. These prints will be accompanied by a small explanation as to why they were the chosen spaces to be measured.

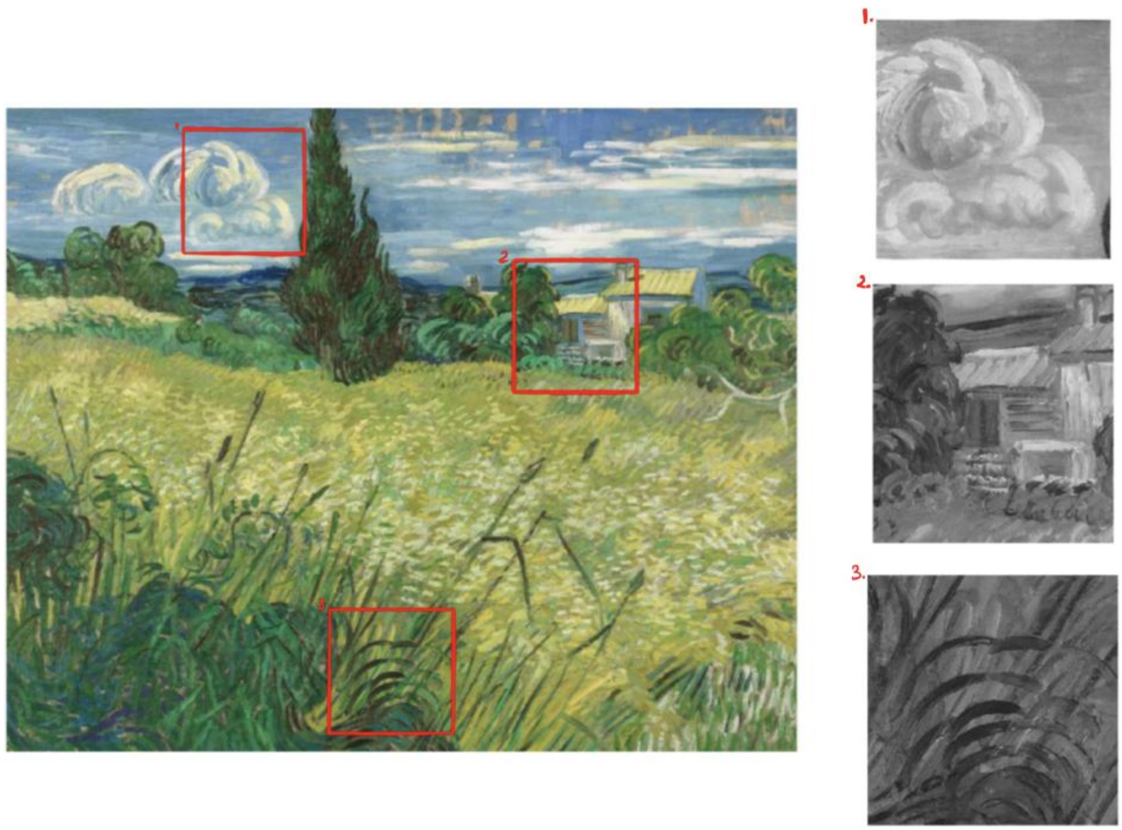


Figure 2-2 3D Print Explanation Interactive

2.3 Brushstroke Interactive

The brushstroke interactive will be formed using the same process as the Comparison Boards and 3D Print Explanation. To complete this element of the exhibit, three brushstrokes at varying widths will be painted. These brushstrokes will then be measured and printed. The prints will be placed on a low surface for children to feel the three-dimensional topography to determine which brush bristles made which impacts in the paint.

2.4 Confocal Microscopy Elements

2.4.1 Microscope Walk-Through

Towards the back of the exhibit there will be a walk-through of the inside of a confocal microscope. This display will have markers on the ground labeling the elements of the microscope, as well as arrows to show where light rays are being directed.

2.4.2 Inner Workings Diagram

Inside the area of the confocal microscopy walk through, there will be a diagram of the inner workings of the microscope that gives detail on how it works to measure surfaces.

2.5 Information Boards

Throughout this exhibit's design, the goal is to make sure that there is engaging information for all ages. To achieve this, the information boards will be placed throughout the exhibit. These need to be simplistic yet graphically appealing. Table 2-1 describes the topics covered.

Information Board	Description
Surface Metrology	This board will share information about what Surface Metrology is and its possible applications
Sensofar	This board will have pictures of the Sensofar itself and descriptions of how it works.
Impasto	These boards will go over what the impasto art style is and some of the biggest artists that contributed to it.
Process	This board will tie the science to the art. It will explain and display pictures of the actual project that led to the exhibit's production.

Table 2-1 Information Board Types

3 TECHNOLOGIES

In designing this exhibit, multiple technologies were used. To analyze and capture measurements of the artwork, a Sensofar 3D surface profiler microscope was used. The data captured was processed with multiple software applications and then printed using a Creality Ender 5 Fusion Deposition Modeling (FDM) 3D printer to create the displays and interactives. Finally, design software was used to create the exhibit's displays and informational placards.

3.1 Sensofar

The Sensofar S Neox is a 3D optic profiler microscope that is used in the WPI Surface Metrology Lab to analyze surface topography with a scale of micrometers. This equipment uses a range of features, including confocal microscopy, focus variation, phase shift interferometry and coherence scanning interferometry.

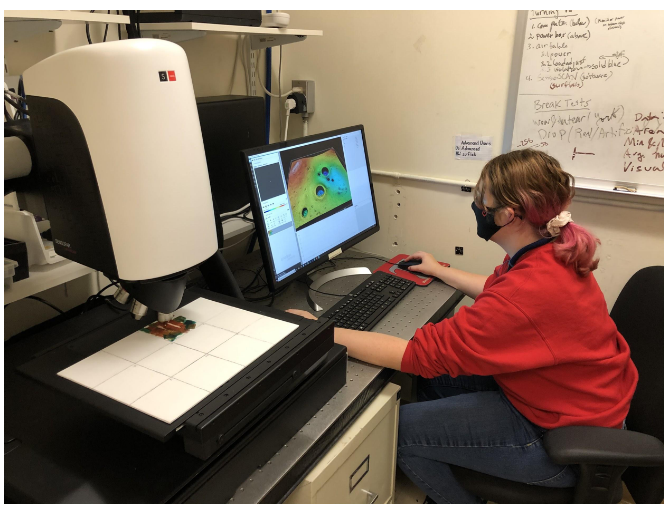


Figure 3-1 Scanning Using the Sensofar

This project is focused on using confocal microscopy and a 5X lens to focus on the texture that comes from the Impasto Art Style that contributes to the depth of the painting. Sections of the paintings are measured and stitched together into a rendering and saved as Sensofar (.plux) files, as well as, Standard Tessellation Language (STL) files to be used in the process of making 3D printed versions of the collected measurements.

3.1.1 Confocal Microscopy

Confocal microscopy is a method of measuring a surface's topography without touching the specimen. This no-contact method is an important process, especially for the art that is being measured. Confocal microscopy was invented in the 1950s by Marvin Minsky who is also one of the godfathers of artificial intelligence. Confocal microscopy was invented because the -then current- process of using fluorescent microscopes had some serious drawbacks. When using fluorescence microscopy, the light that is used to detect the topography of the specimen is high-intensity UV light. This continuous exposure to high-intensity Ultra-violet light caused photo bleaching (Quick Biochemistry Basics 2018). Another issue was that, although some images above and below the focal plane of the sample can be seen, the images that were obtained were often blurred. The confocal microscope is mostly the same as a fluorescence microscope, however, it has two major modifications. While a fluorescent microscope used a mercury arc lamp as its source of light, a confocal microscope uses a laser light. It can also be seen that in a confocal microscope there is a pinhole in front of a digital camera/detector unlike the fluorescence microscope which had no pinhole. This change allows only the light from one focal plane to be in focus while the above and below focal planes are blocked out.

When a confocal microscope is being used, the laser is focused onto a small region of the specimen. That area is then captured by the digital camera. This is repeated multiple times over a large area, as well as over multiple focal planes at different heights. The images captured are stitched together with software to make a 3D model.

3.2 Software

Two different types of software were used during the creation of this museum exhibit. The first type is the analytical software used to measure, analyze and render 3D prints of the Impasto artwork. The second type is design software used to develop the exhibit's floor plan, visuals, and interactive mock-ups.

3.2.1 Analytical Software

Multiple software tools were used while measuring the artworks and manipulation the data to allow it to be printed.

Software	Description
Sensofar	The software included with the Sensofar microscope directs it to which areas are to be measured. It then records the Sensofar data and stitches the areas together to create a 3D rendering.
Mountains	Mountains is a program used for analyzing surfaces. This software can take the data from the Sensofar and display it in a comprehensive manner.
F 360	Fusion 360 is a tool for modeling of 2D and 3D objects that can also be used to animate your designs, render objects, simulate loads, and prepare models for CNC machining.
3D builder	3D builder is Microsoft's 3D modeling software that allows the design of 3D models
Meshmixer	Meshmixer is a software used for working with triangle meshes.
Cura	Cura is a 3D slicing software that creates the g-code for printing

Table 3-1 Analytical Software Used

3.2.2 Design Software

Adobe Software products were used for the creation of the exhibit's signage and interactive mock-ups.

Software	Description
Adobe Illustrator	An industry standard design application for creating designs with shapes, color, effects, and typography. Used to create mock-ups of the exhibit's displays, interactives and informational signage
Adobe Photoshop	An industry standard application for image editing and manipulation. Used to edit and correct photographs for the exhibit.

Table 3- 2 Design Software Used

3.3 Three-Dimensional Printing

For the exhibit interactives, 3D prints were required for the selected painting measurements and the brushstroke experiments. After the measurements were taken by the Sensofar, they were saved as .plux files. However, this type of file cannot be used to produce 3D prints. To initiate the 3D printing process, the measurements were also saved as STL files. The generated STL files only saved the surface level data points which were infinitely small and unprintable.

To make the STLs printable, they had to go through a tedious conversion process. First, STLs would be pulled into Fusion 360. The software limits the area of a model to about 10,000 triangles. However, the files that were measured for this project were closer to numbers like 70 million. This led to the need to reduce the files until they were comfortably under the Fusion 360 limit. Once the STL's were of a good size they could be converted. Fusion 360 interprets STL’s as mesh objects. It has the ability to convert this mesh into data that F360 can understand. Fusion 360 conversion makes part files from the STL files. A base is then added to this new part file and it can then be re-saved as a new STL. This new STL can be put into Cura and printed.

In some cases, there were anomalies to this process because measurement files were too large. To overcome this, the following procedures were carried out. If the file was too large for Fusion 360 and too large for a similar software, 3D Builder, it would then be pulled into Mesh Mixer, a third similar software. Here, the file would be split into smaller sections. Once it was cut in half, each half could be moved into 3D Builder individually and split again. After being broken down into quarters, the files could then be moved to Fusion 360 for the addition of a base. Furthermore, if it was too large for Fusion 360, but could open in 3D Builder, it would simply be split into smaller files through that program. Once back into Fusion 360, the files would follow the process as described above.

3.4 Artwork

In order to make prototypes for the elements that were envisioned for this exhibit, Impasto artworks had to be created. While it would have been preferable to use better known professional artworks by artists like Rembrandt or Van Gough, this was not feasible for this small project. Additionally, getting these larger works under the Sensofar lens would have been impossible. Larger professional artworks tend to display changes in characteristics over larger areas that are too large scale for the Sensofar. The smaller designed artwork was created with changes over smaller, more easily measured, areas.

3.4.1 Impasto Art

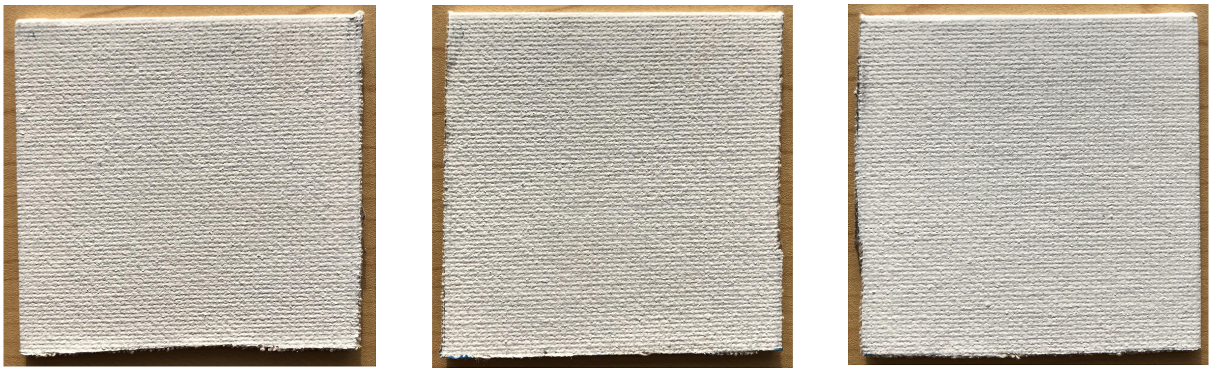
Impasto was chosen for this project because of the style's guaranteed dramatic topography. Most other art techniques remain close to the canvas and are often covered in varnishes that make it even more difficult to analyze. "A painting technique, impasto, is a thick application of paint that does not attempt to look smooth. Instead, impasto is unabashedly proud to be textured and exists to show off brush and palette knife marks. Just think of nearly any Vincent Van Gogh painting to get a good visual" (Esaak 2019).

3.4.2 Media Selection

To determine how to best create and measure artwork, prototyping samples were made and measuring experiments were performed. To conduct these experiments, a small canvas was split into eight 3" X 3" sections and labeled alphabetically.

3.4.2.1 Initial Measuring Investigations

Initially, the first three samples, A-C, were painted using different application methods (fig 3-2). These first 3 samples were used to get more comfortable with how the Sensofar is operated and help determine how different painting techniques would be measured by the Sensofar.



A - sponge brush   B - paint brush   C - finger painting

Figure 3-2 White Painting Technique Samples

Samples A-C were painted with a white acrylic paint using different techniques. Sample A - sponge brush, Sample B - paint brush and Sample C - a finger painting method. Each method produced different results as shown in table 3-3.

Sample	Method	Results
A	Sponge Brush	This measurement had many craters caused by more aeration in the paint. This caused large variances in the measured maximum and minimum heights.
B	Paint Brush	This application had no air bubbles, but was thinner which allowed the canvas texture to be seen through the paint.
C	Finger Painting	This was a very smooth application method that resulted in thick coverage that blocked most of the canvas texture, and had a wavy appearance. Fingerprints were also visible

Table 3-3 Painting Techniques Described

Once comfortable with the equipment and measuring techniques, the brushstroke topography was analyzed.

3.4.2.2 Brushstroke Topography

The fourth section of canvas, Sample D (fig 3-3), was also used for experimentation. In particular, this test was aimed at determining whether or not the Sensofar could detect brushstroke topography, as well as, paint strokes overlapping. The results from this experiment showed the Sensofar could detect & measure both, the brush stroke textures, and the overlapping of colors. These positive results ensured that the project could progress with this selected equipment.

Figure 3-3 Brushstroke Topography Sample

While measuring this sample, it was realized that the acrylic might not be the best media to use. Not only did the paint settle as it dried, but because it is water soluble it resulted in a much thinner covering where the canvas texture could interfere with measurements.

3.4.2.3 Acrylic Vs. Oil Based Painting

As described in section 3.4.2.2, the acrylic painting had problems with coverage and therefore it was determined that another paint type might provide more accurate results. Samples E and F (fig 3-4 & fig 3-5 respectively) were both painted in the Impasto art style, but with different paint types. Sample E was painted with acrylic paint while painting F was painted with an oil paint.

Figure 3-4 Sample E - Acrylic Paint

Figure 3-5 Sample F - Oil Paint

When preparing to take a measurement on the Sensofar, the "Z-scan" section, seen to the right of figure 3-6 and enlarged in figure 3-7, must be filled in. This lets the microscope know the maximum and minimum height it has to account for when taking images. Before even taking these measurements, it can be observed that the range in height of Sample E is significantly lower than that of Sample F, shown below in table 3-4.

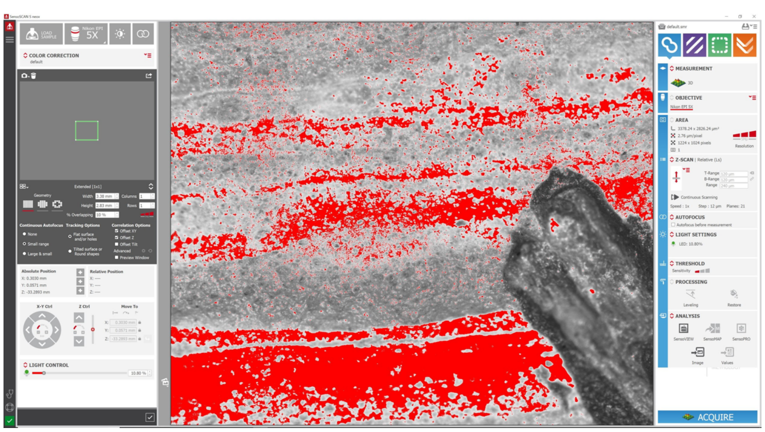


Figure 3-6 Sensofar UI

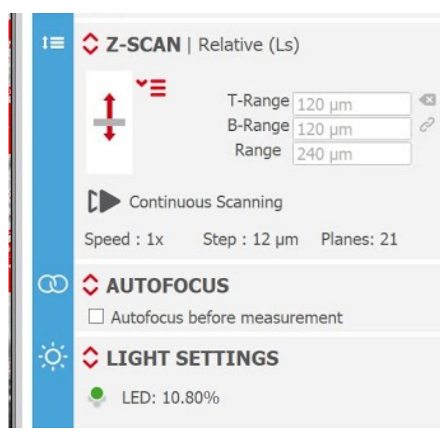


Figure 3-7 Sensofar Z-Scan Menu

	Z Top	Z Bottom	Z Range
Plain Canvas (control)	-33460 µm	-32721 µm	739 µm
Acrylic Painted Bird	-32701 µm	-33677 µm	976 µm
Oil Painted Bird	-34263 µm	-31764 µm	2499 µm

Table 3-4 Topology Range

Given that the topography range for the acrylic painting was far lower than the range of the oil painting, the oil painting was chosen for the prototyping. It can also be observed in fig 3-8 & fig 3-9 below, that the rendering of the oil painting came out far clearer than the rendering of the acrylic. With the positive results from the oil-based impasto samples over acrylic, the remainder of this project was completed with strictly oil based items.

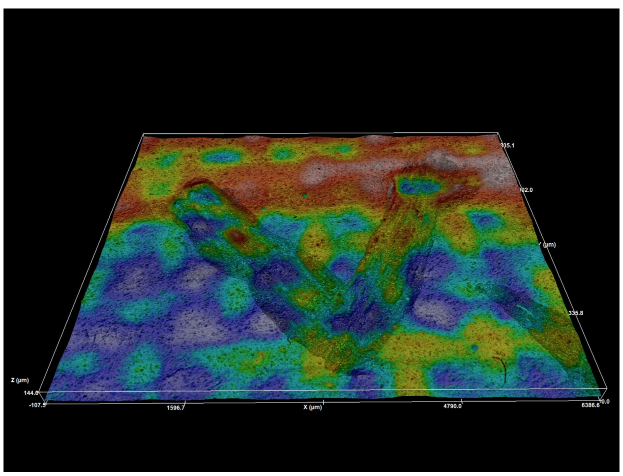


Figure 3-8 Acrylic Paint Rendering

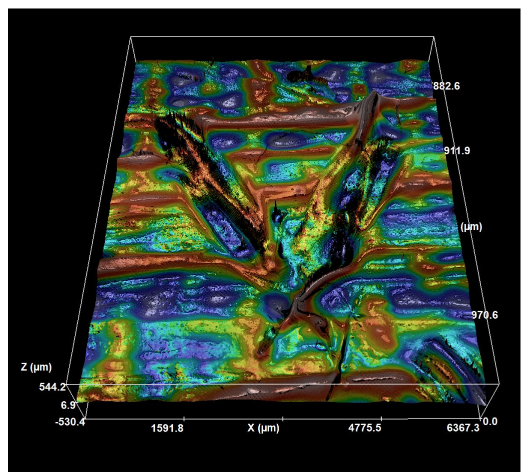


Figure 3-9 Oil Paint Rendering

4 INTERACTIVES PRODUCTION

Once the painting, technological and printing processes were completed, they could be combined to produce the interactive elements of this exhibit as described in section 2.

4.1 Comparison Board Production

Creating the comparison board (fig 4-3) as described in section 2.1 first required capturing (fig 4-1) three sample sections from the oil painting with the Sensofar. The samples were created by measuring areas from the original oil painting (see section 3.4.2). These three areas were from the leftmost bird, the sun, and the middle flower on the bush. Once measured, the files were converted into the correct format (section 3.3) for printing, these final 3D prints can be seen in figure 4-2.

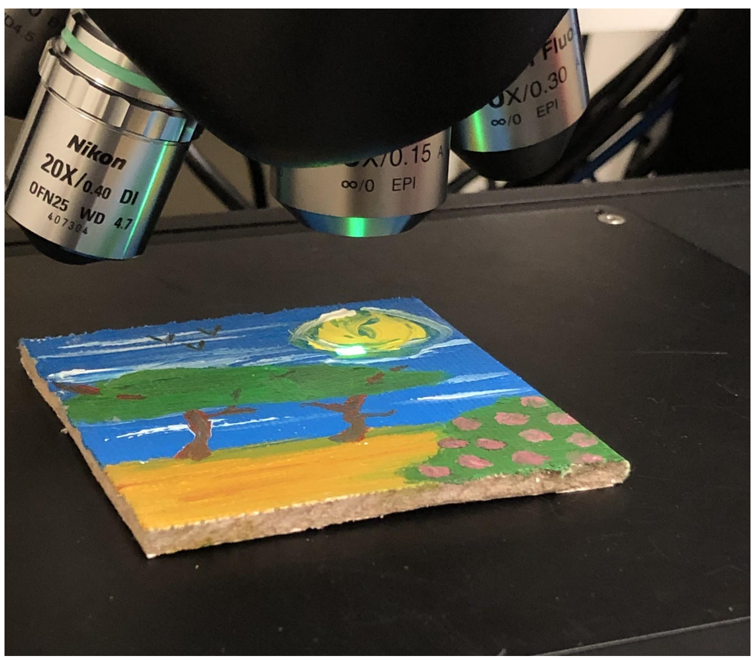


Figure 4-1 Measuring the Painting with the Sensofar

3D Bird 3D Sun 3D Flower

Figure 4-2 3D Printed Samples

The final poster, the integrated 3D prints and instructions that guide users to interact with the Comparison Board were combined to make the exhibit interactive.

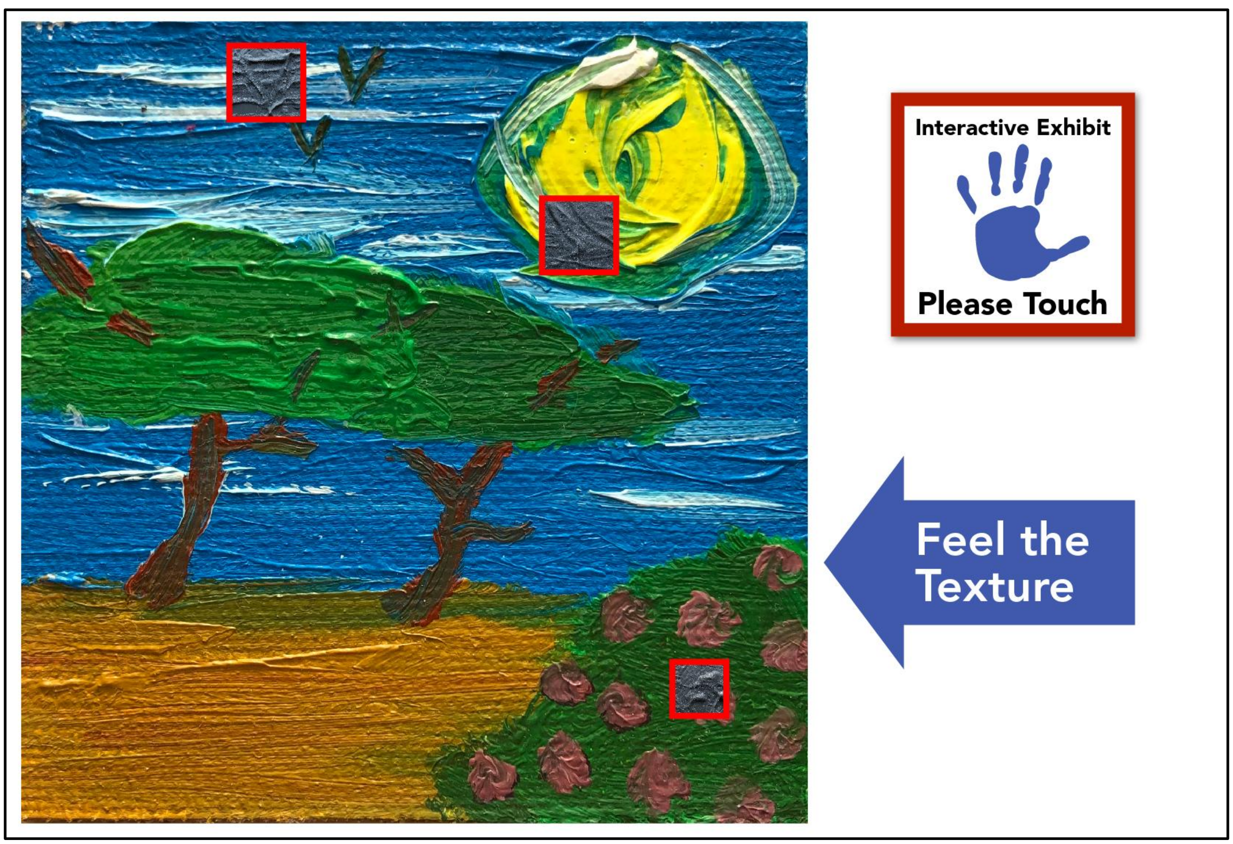


Figure 4-3 Comparison Board Display

4.2 Three-Dimensional Print Explanation Production

The 3D Print Explanation Display (fig 4-4) will house the original oil painting that was created for this project. To the right of the original will be the original 3D prints with a small explanation as to why that area was selected. To obtain these prints, the same process for the creation of 3D elements described in section 4.1 was followed.

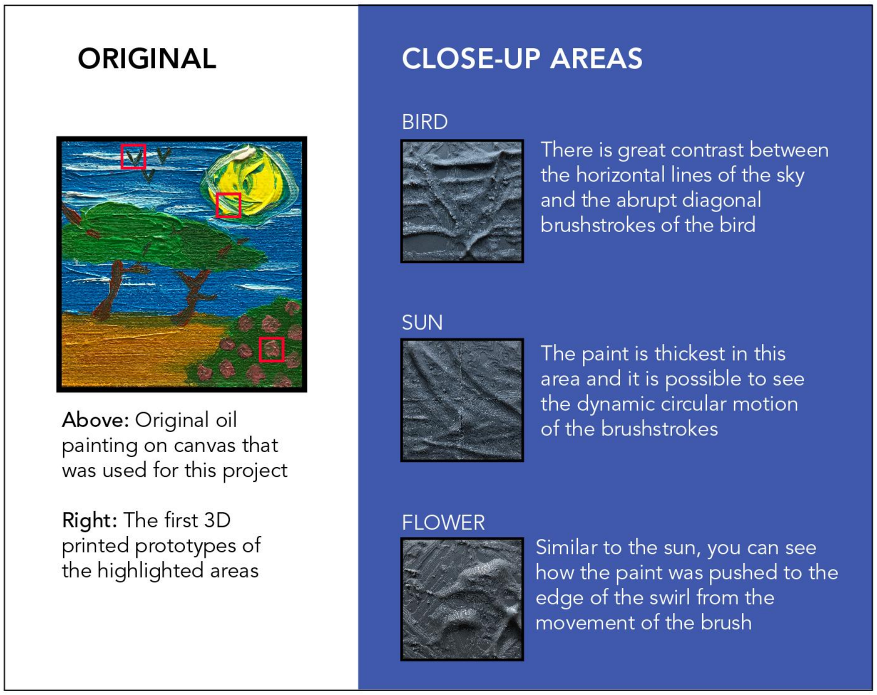
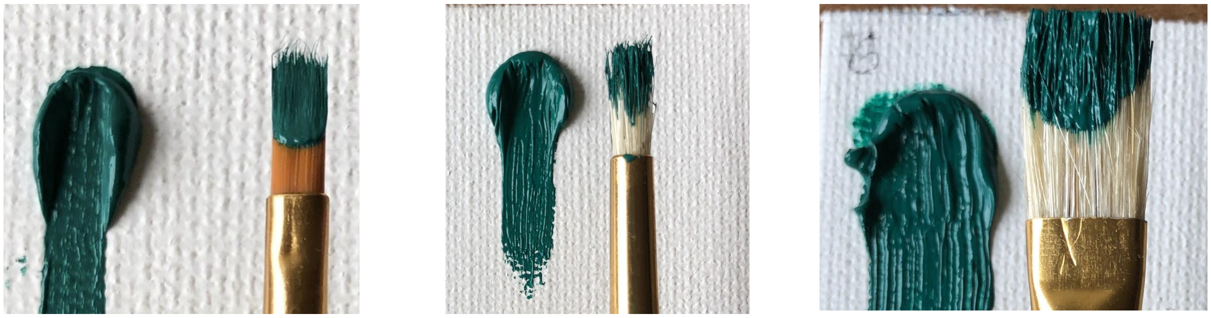


Figure 4-4 Three-dimensional Print Explanation Display

4.3 Brushstroke Interactive Production

This portion of the exhibit is designed to observe brushstrokes isolated from the painting. To create the brushstroke interactive, as described in section 2.3, three dollops of paint were put on separate sections of canvas. Using 3 different sized brushes (fig 4-5) the dollops of paint were imprinted with a brushstroke.



Small Brushstroke Medium Brushstroke Large Brushstroke

Figure 4-5 Brushstroke Impressions

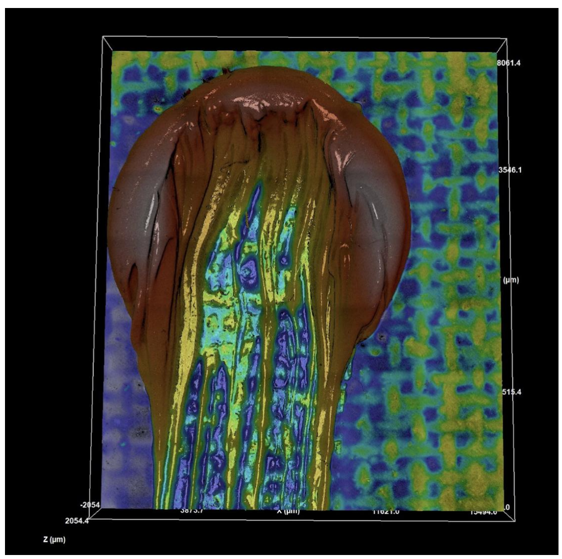


Figure 4-6 Medium Brushstroke Rendering

Examples of the medium brushstroke rendering from the Sensofar measurement is shown in figure 4-6. Similarly, as in section 4.1 and 4.2, the measured imprinted dollops were converted via software and 3D printed for this interactive (figures 4-7, 4-8, and 4-9). The 3D prints of the brushstrokes will be placed in sections A, B, and C of the interactive shown below in figure 4-10. Behind the row of brushstrokes, there will be slots for children to guide brush icon pegs along, in order to determine which brush led to which brushstroke. Once selected, the participant can lift the paint can lid to check their answers.

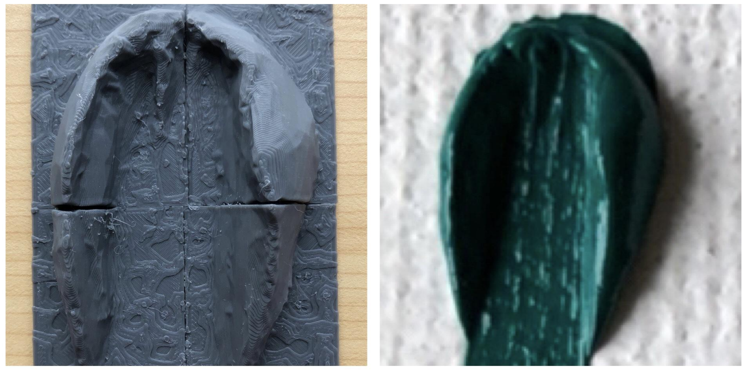


Figure 4-7 Small Brushstroke 3D printed and Original

Figure 4-8 Medium Brushstroke 3D printed and Original

Figure 4-9 Large Brushstroke 3D printed and Original

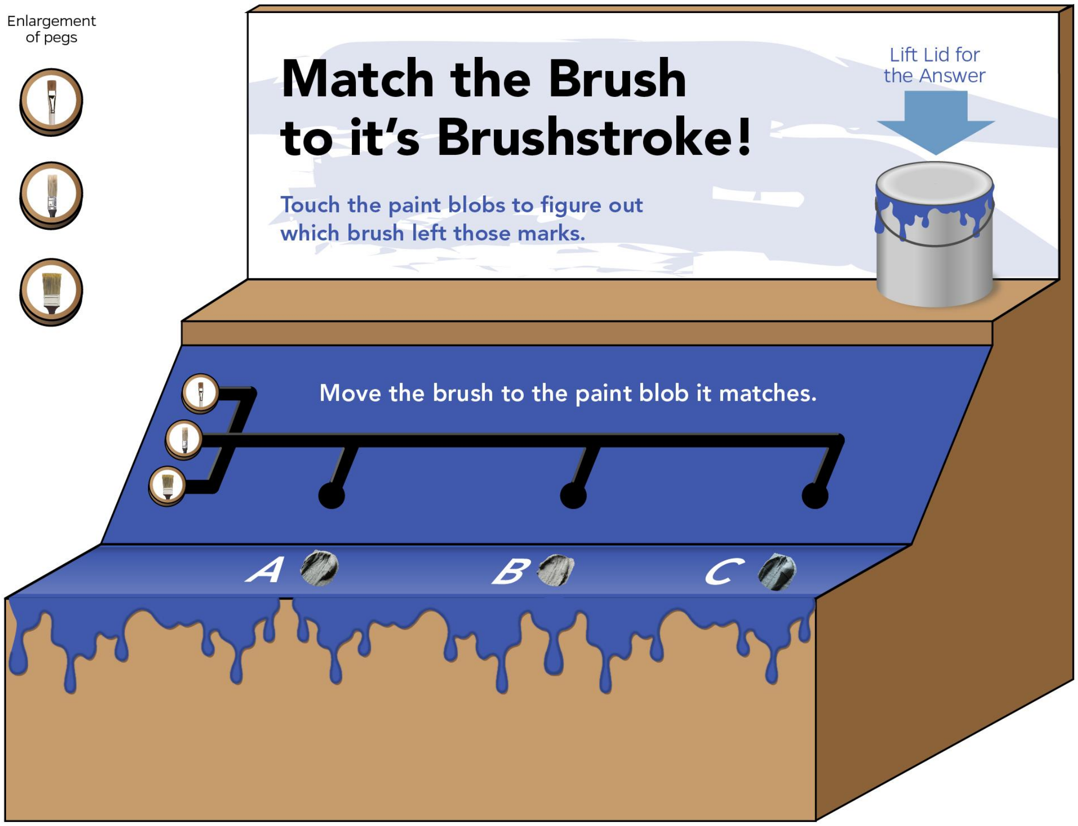


Figure 4-10 Brushstroke Interactive

4.4 Confocal Microscopy Elements Production

4.4.1 Microscope Walk-Through Production

Figure 4-11 shows the final floor rendering of the diagram described in section 2.4.1 that allows visitors to walk-through of the inside of a confocal microscope.

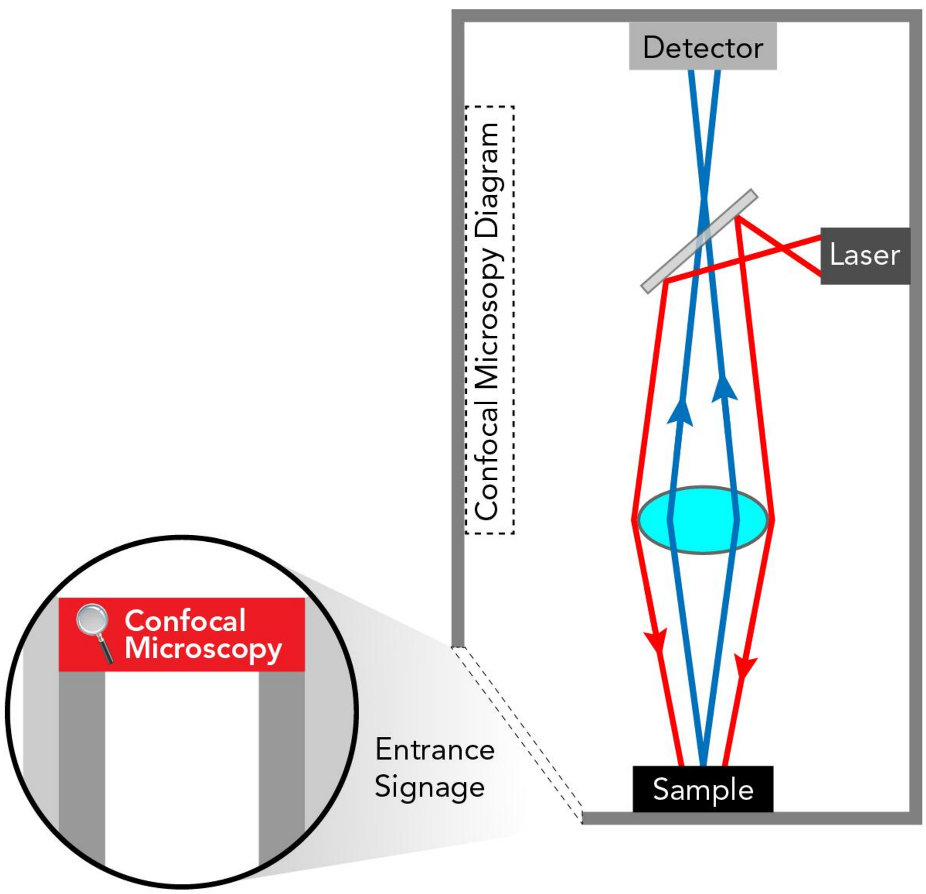


Figure 4-11 Confocal Microscope Walk-Through

4.4.2 Inner Workings Diagram Production

The wall display, in figure 4-12, labels the interior of a confocal microscope to give a more in-depth look at how it can measure surfaces.

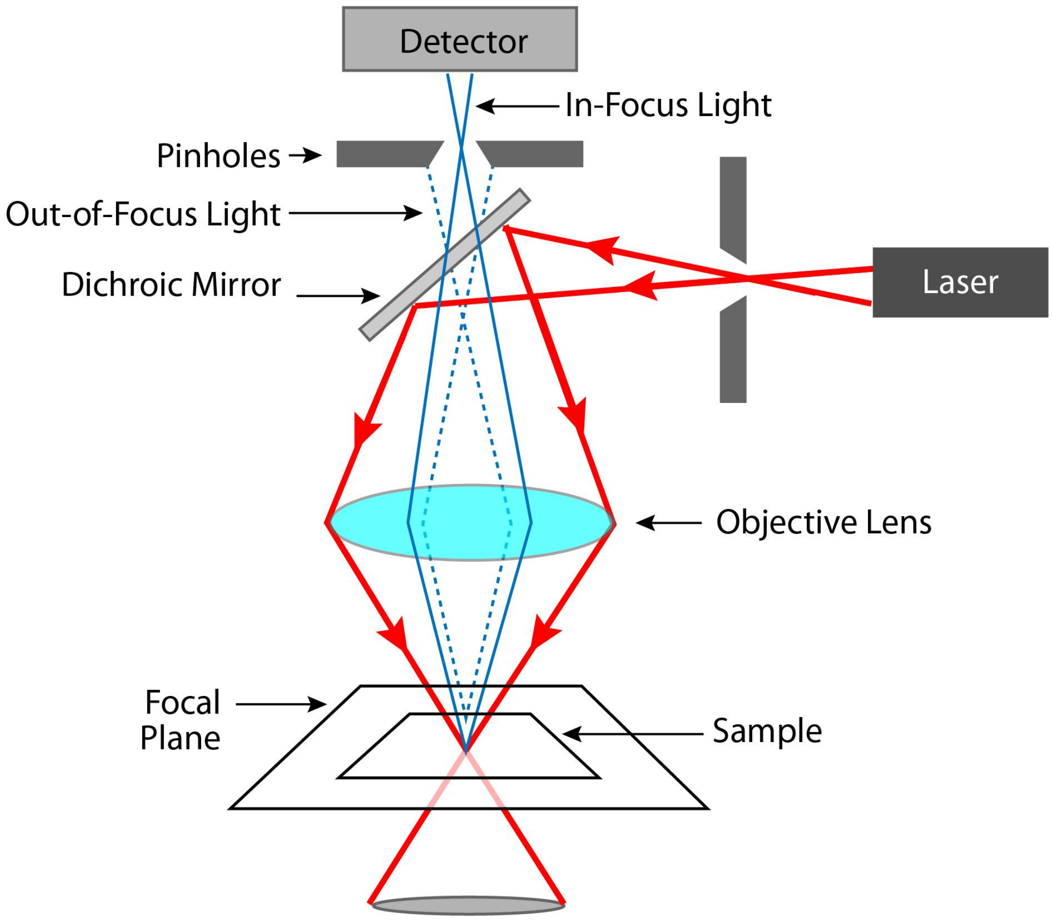


Figure 4-12 Confocal Microscope Inner Workings Diagram

4.5 Information Boards Production

The Information boards that will be displayed throughout the exhibit range from introduction of surface metrology to Impasto Artists. Their completed designs are shown below.

4.5.1 Surface Metrology Board

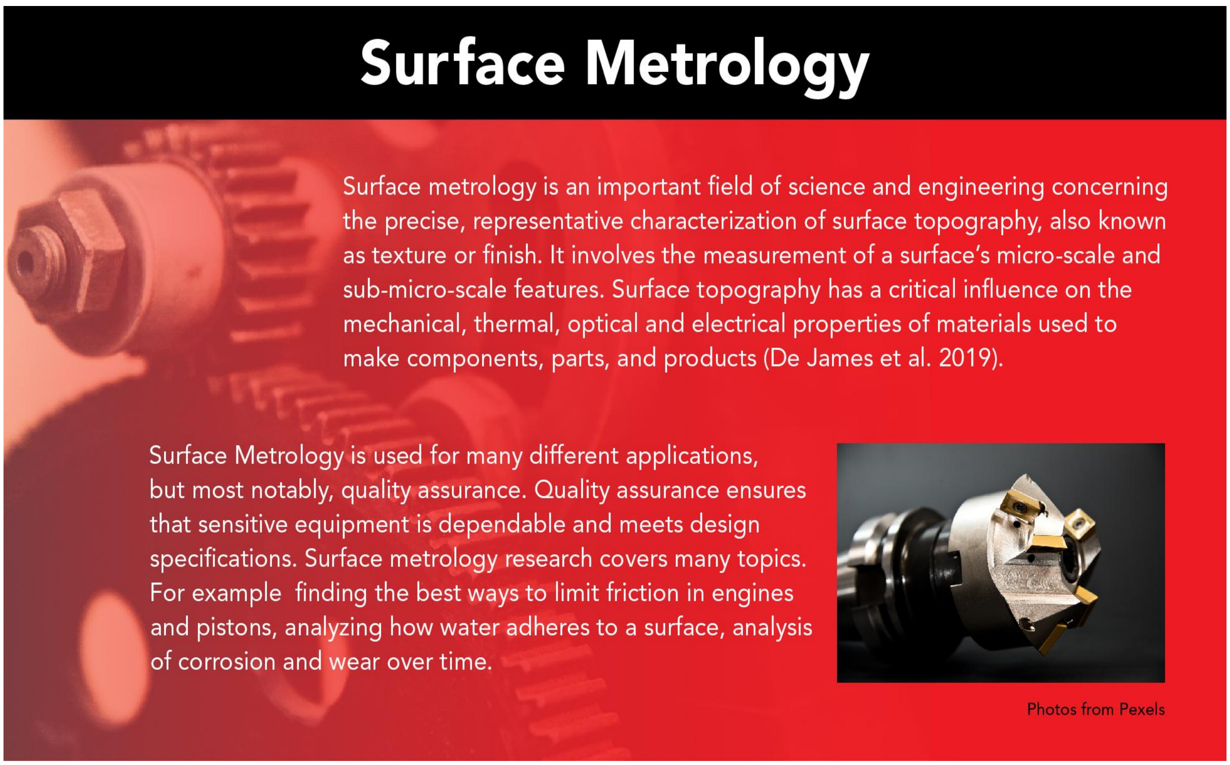


Figure 4-13 Surface Metrology Informational Board

4.5.2 Sensofar Board

Figure 4-14 Sensofar Informational Board

4.5.3 Impasto Boards

Figure 4-15 Impasto Definition Informational Board

Figure 4-16 Impasto Artists Informational Board

4.5.4 Art to Three-Dimensional Print Board

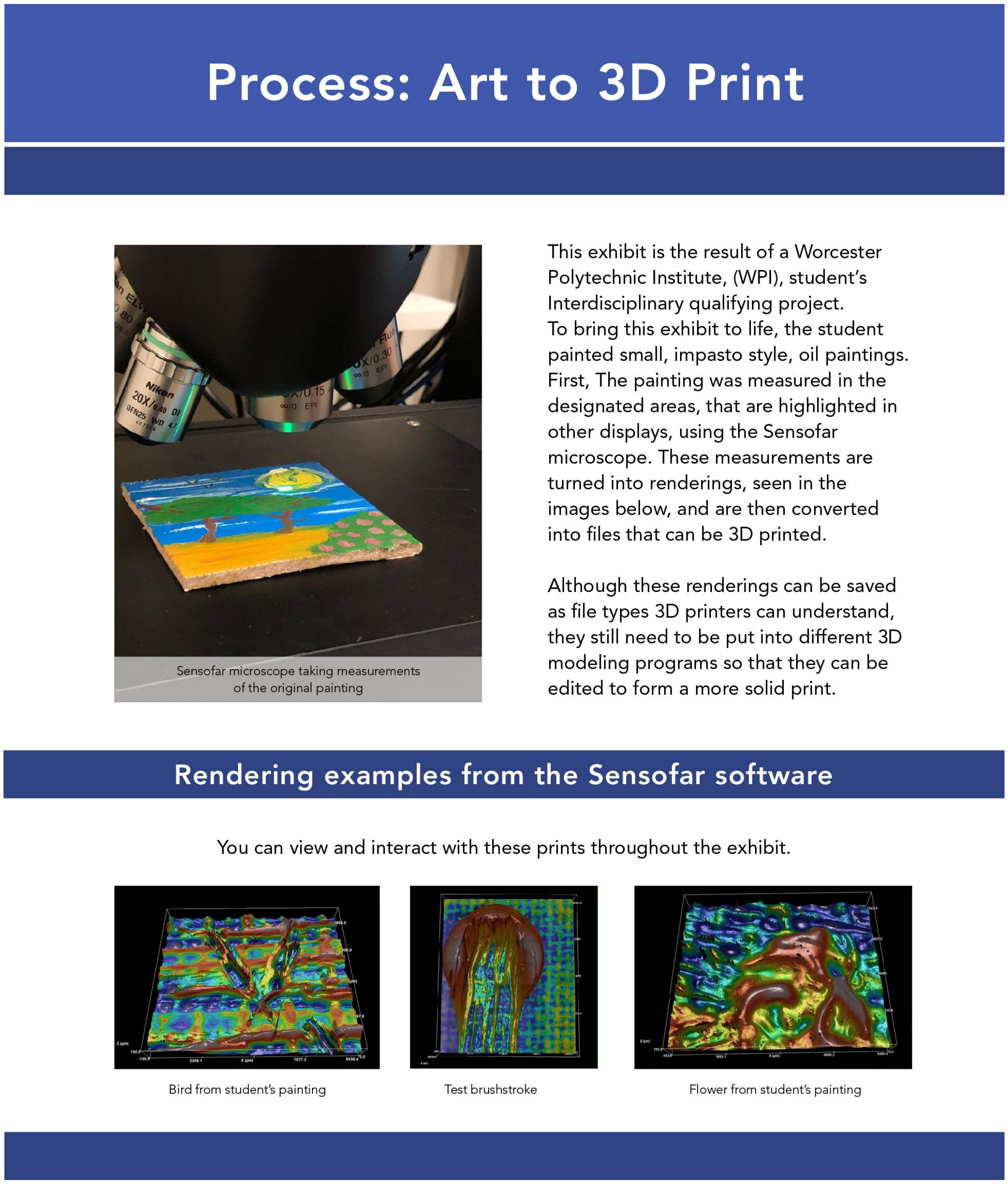


Figure 4-17 Art to Three-dimensional Prints Informational Board

5 RESULTS

The results of this project's research and design culminate with a final museum exhibit. Figure 5-1 shows the Exhibit's main entry display. It will welcome visitors and immediately inform them that unlike most museum exhibits, this one will be interactive and touchable. The finalized exhibit floor plan is laid out such that visitors can traverse through the exhibit via two distinct pathways (fig 5-2).

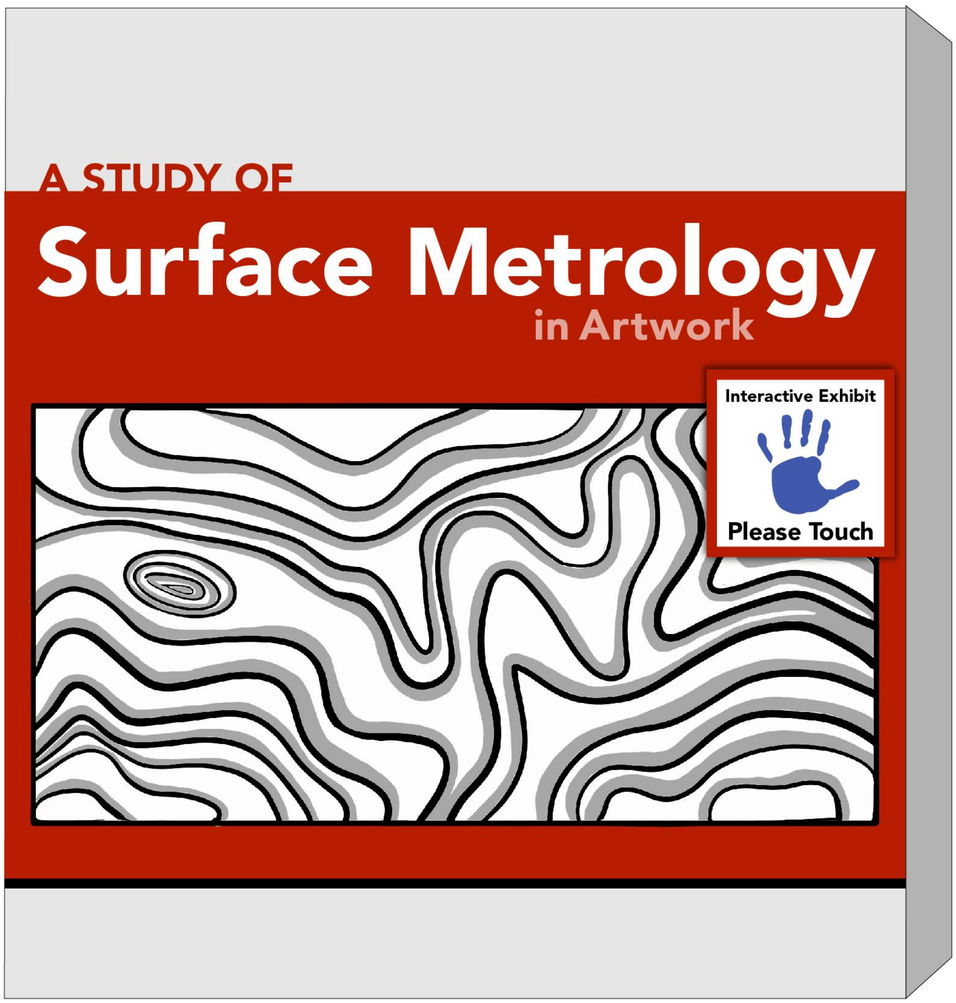


Figure 5-1 A Study of Surface Metrology in Artwork Museum Exhibit *Entrance Display*

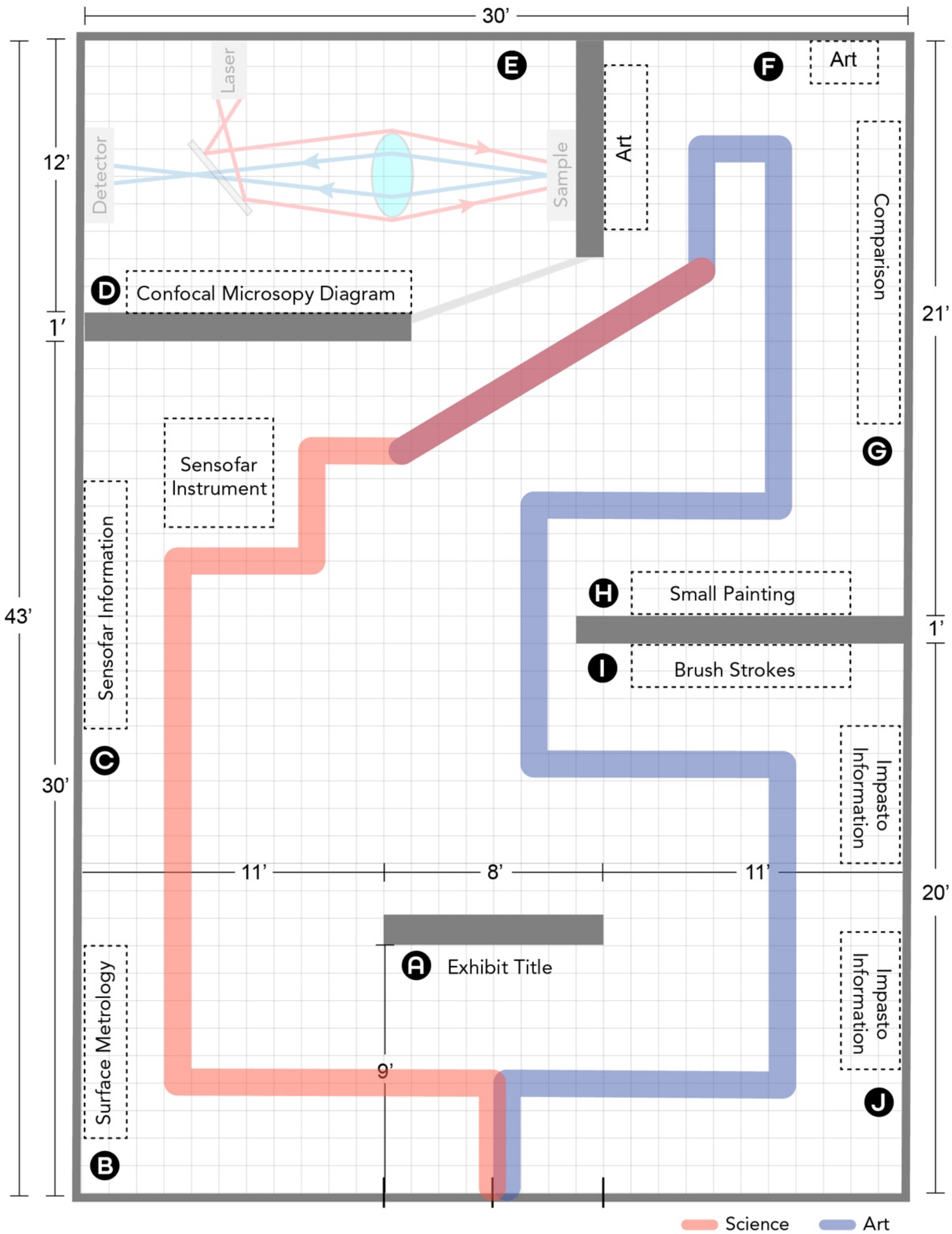


Figure 5-2 Finalized Exhibit Floor Plan

Table 5-1 shows a Map Key with floor plan identification, displaying which letter corresponds to which corresponding figure from this paper

Floor Plan ID Letter	Paper Figure Number
A	*Figure 5-1 A Study of Surface Metrology in Artwork* Museum Exhibit *Entrance Display*
B	*Figure 4-13 Surface Metrology Informational Board*
C	*Figure 4-14 Sensofar Informational Board*
D	*Figure 4-12 Confocal Microscope Inner Workings Diagram*
E	*Figure 4-11 Confocal Microscope Walk-Through*
F	*Figure 4-17 Art to Three-dimensional Prints Informational Board*
G	*Figure 4-3 Comparison Board Display*
H	*Figure 4-4 Three-dimensional Print Explanation Display*
I	*Figure 4-10 Brushstroke Interactive*
J	*Figure 4-15 Impasto Definition Informational Board* *Figure 4-16 Impasto Artists Informational Board*

Table 5-1 Floor Plan ID Key to Exhibit Elements

The first pathway, to the right, is oriented to the artistic side of the exhibit as it opens with informational boards about the Impasto art style and includes example artists and their artworks. The visitor then moves to the Brushstroke Placards where they interact with its corresponding matching activity (section 4.2). Turning the corner, they will be shown the 3D print explanation display where they can observe the enlarged areas that were studied from the original painting. Continuing on, they will reach the comparison board which is a tactile feature where visitors can see where the 3D prints belong in the context of the original painting and feel the topology of the artwork. At this point the visitor is presented with the introduction of the science behind the creation of the exhibit. This is the main overlapping component of the Art and Science pathways. From here the visitor enters the scientific pathway and travels through the technology displays toward surface metrology.

Conversely, if the visitor enters the exhibit and goes to the left, they are oriented towards the scientific analysis of the artwork. They are presented with an explanation of surface metrology. Next, the visitor is presented with information about the Sensofar microscope. Entering the back corner of the exhibit they will see information about the device and enter a walkable model of the interior of a confocal microscope where they can visualize how it works. With the introduction of surface metrology and the confocal microscope completed they will enter the overlapping component of the exhibit and begin traveling toward the artistic portion.

These two pathways create multiple ways of enjoying and learning about the exhibit and can be traveled differently by different visitors.

6 CONCLUSION

One of the goals of this project was to teach children about Surface Metrology and Impasto artwork. This combination was chosen as a real-world example of STEAM. It also aimed to design an art museum exhibit that features tactile displays that keep young visitors engaged while learning. These goals were accomplished through the research and experimentation with the Sensofar Microscope that led to determining the best method for creating and measuring artwork. These measurements were then converted into three-dimensional versions of the paintings. Each print was then applied to the design of the interactive displays to give a better visualization of how visitors would experience them in-person, resulting in the finalized "*Study of Surface Metrology in Artwork*" exhibit.

7 RECOMMENDATIONS

Oftentimes, the Recommendations section of a paper discusses procedures or processes that the paper's authors would do differently once the project or research has completed. However, most of the recommendations seen here will be items that were on the agenda for the project, but were not completed due to the Covid-19 pandemic.

- More museum observations
- Meeting with more museum curators
- Observing children visiting interactive and non-interactive exhibits
- Interviewing school aged children and their teachers
- Building and testing exhibit prototypes with children

In addition to the procedures that could not be completed due to the pandemic, following researchers may want to consider the following.

- Delving into the analysis of brushstrokes between artists.
- Implementing this exhibit and surveying attendees
- Consider different engineering and science areas that could be explained through art studies.
- Develop more interactives for this exhibit.

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[closed] Survey Link:
https://docs.google.com/forms/d/e/1FAIpQLSe9CcX1x_PpWZ45G8CYVaYZXHBKX4w6_iJOHdcZs3v1yw0Hkg/viewform?usp=pp_url

9 APPENDIX A Field Trip Survey

9.1 Field Trip Survey Questions

The following is a google form survey that was posted to the Worcester Polytechnic Institute's (WPI) Reddit.com page. About 84 students responded. Figure 9-1 shows what respondents saw when taking the short 5 question survey.

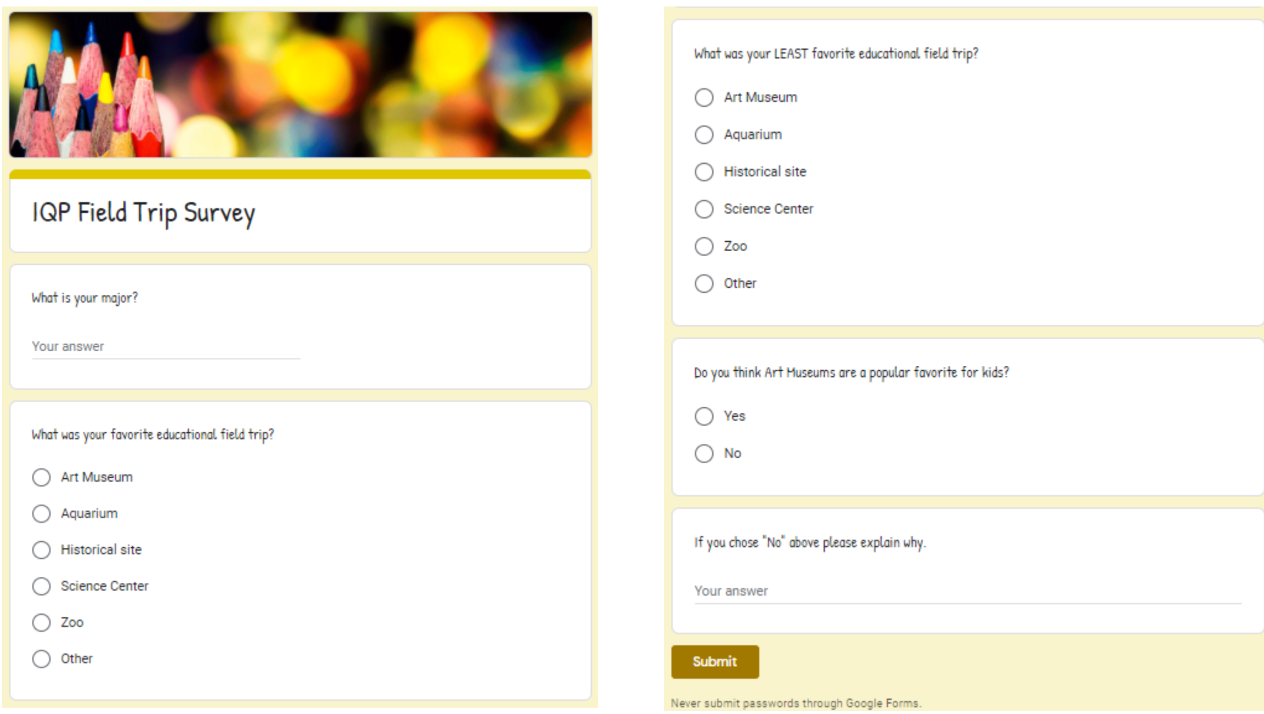

Figure 9-1 Reddit.com Survey

9.2 Survey Results.

The following tables show the results from the Field Trip Survey (section 9.1) questions. Table 9-1 shows the distribution of majors of the survey respondents from WPI.

RESPONDENCE MAJORS	COUNT
Aerospace engineering	4
Architectural Engineering	2
Bio and Biotech pre vet	1
Bioinformatics and Comp. Biology	1
Biology and Biotech	3
Biomedical engineering	11
Chemical Engineering	4
Civil Engineering	5
Computer Science	13
Data science	1
Electrical and Computer Engineering	5
Environmental Engineering	3
Graphic Design	1
IMGD	2
Industrial Engineering	2
Management Information System	1
Mathematical Sciences	4
Mechanical Engineering	16
Psychological Science	1
RBE	3
No Response	1
Total	**84**

Table 9-1 Survey Respondents by Major

Figure 9-2 and Table 9-2 represent the results from the survey question: “What was your favorite educational field trip?”

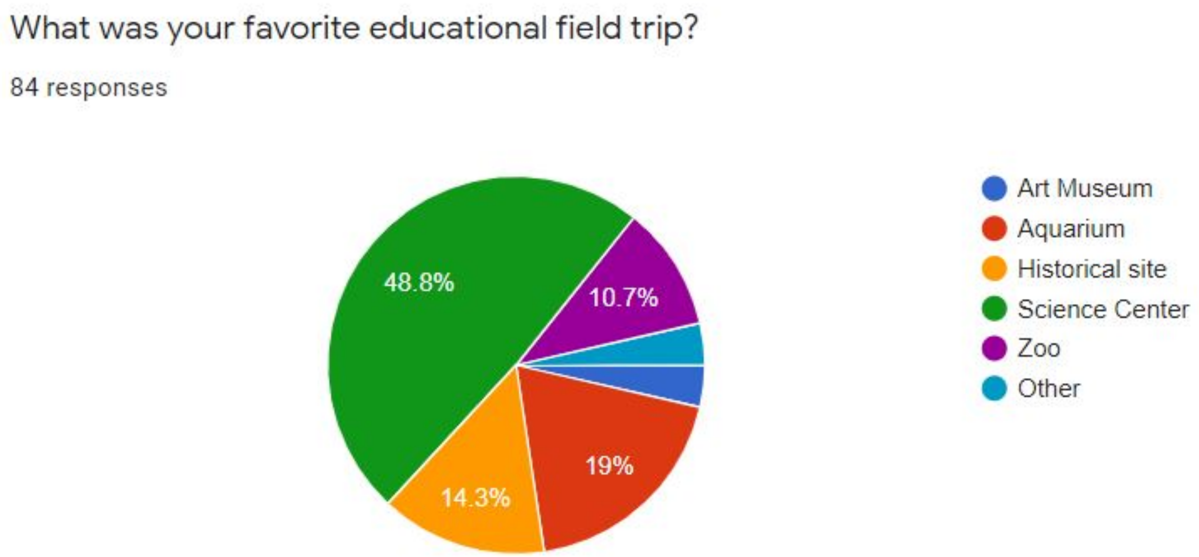

Figure 9-2 What Was Your Favorite Field Trip? Results

FAVORITE EDUCATIONAL FIELD TRIPS		
TYPE	COUNT	%
Aquarium	16	19.0%
Art Museum	3	3.6%
Historical site	12	14.3%
Science Center	41	48.8%
Zoo	9	10.7%
Other	3	3.6%

Table 9-2 What Was Your Favorite Field Trip? Results

Figure 9-3 and Table 9-3 represent the results from the survey question: "What was your least favorite educational field trip?"

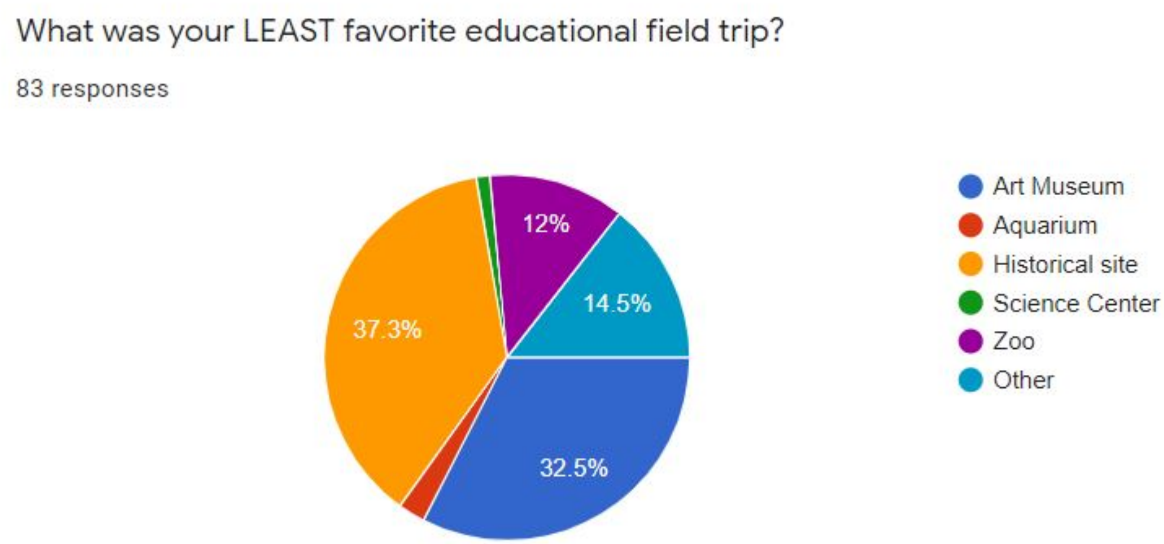

Figure 9-3 What Was Your Least Favorite Field Trip? Results

LEAST FAVORITE EDUCATIONAL FIELD TRIPS		
TYPE	COUNT	%
Aquarium	2	2.4%
Art Museum	27	32.5%
Historical site	31	37.3%
Science Center	1	1.2%
Zoo	10	12.0%
Other	12	14.5%

Table 9-3 What Was Your Least Favorite Field Trip? Results

Figure 9-4 and Table 9-4 represent the results from the survey question: “Do you think Art Museums are a popular favorite for kids?”

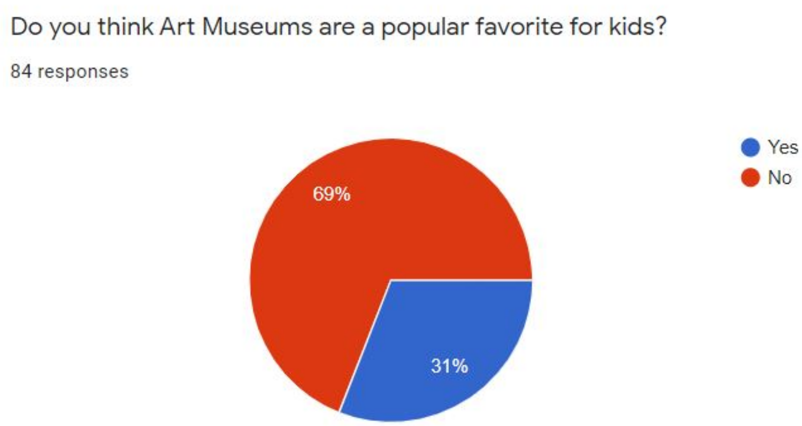

Figure 9-4 Do you think Art Museums are a popular favorite for kids? Results

Do you think Art Museums are a popular favorite for kids?		
No	58	69%
Yes	26	31%

Table 9-4 Do you think Art Museums are a popular favorite for kids? Results

Finally, Table 9-5 Shows the free form results to the question “If you chose ‘No’ above, please Explain.

If you chose "No" above please explain why.
They are boring, you can’t touch anything
Art in museums, as it is mostly paintings (namely portraits of people from many generations ago), is generally boring and many children agree with this statement especially. Most children lack the intellectual depth to analyze art thoughtfully and therefore do not really gain anything from looking at art in a museum. I myself agree with this even today, at 21 years old.
Kids do not understand/aren’t as interested in art.
Kids generally aren’t the target audience for art museums
I feel like unless there’s something interactive kids lose interest fast.
Often younger kids aren’t very engaged by art museums. There isn’t much for them to interact with, which for me as a kid made them a bit boring, particularly if the artists on exhibit were less well-known.
The child mind wants to play with things not stare at a wall
Unless it's an art museum that specifically caters to students through programming etc., I feel it's hard for students to connect with and understand art due to its general lack of accessibility.
Kids generally find art to be boring (or at least classical art)
Going on field trips usually meant doing something hands-on or something engaging. However art museums are less interactive, it's more observing. Kids want to be active and want to be involved/engaged
Depending on age, they might not be able to appreciate what they’re seeing. I think it’s also important for teachers to “set the scene”: to explain why they’re visiting the art museum, so kids understand what they’re looking at.
I think a kid would be more interested in the tactile activities that be done at the other locations. Also kids get very little exposure to art, especially a lack of awareness when going to an art museum as a kid (famous artists, different mediums of art, techniques, the era, how to analyze art) A kid going to an art museum would likely just look at a painting and be unable to discuss it or gain much educational value. However, I totally believe art is important for kids to get exposed to. I think art museums are more geared towards adults or older kids/teenagers.
I don't think that many kids enjoy the refinement and serenity of visiting an art museum. I love science as much as the next engineer, but I also enjoy the balance between the arts and sciences. I remember most of my classmates as kids disliking both actually.
Little kids don’t have the attention span to stare at art for a long time
Art museums tend to be less interactive for children, making them only interesting to kids who already have some appreciation of art and have the focus and patience to look at painting after painting. Also, art museums tend to be quiet places, and kids just aren’t quiet, making it a less welcoming environment than a busy zoo, aquarium, or science museum.
I believe kids need something more interactive to stay focused and both enjoy and learn something from the trip which can be difficult to implement at an art museum
Maybe kids do not have the patience or the critical eye to really appreciate art.

Art museums are awesome and I appreciate them more now, but I think as a kid they weren't framed in a fun way. It has to do with how teachers/guides present them to kids.
Depending on the age younger kids may need more stimulation like a science museum to keep them engaged. Taking older kids interested in art to an art museum makes sense but it’s hard to enjoy something you’re not interested in
I found art museums to be pointless and I got bored easily
They’re typically boring and not interactive.
Kids under 13 probably don’t see the beauty in art.
They aren't as fun as other options.
Often, art museums are not geared towards kids and there aren't a lot of activities to keep kids engaged.
Kids can't really appreciate art. At least with something like aquariums there's like "hehe check out the cool fish"
I think it depends on the type of exhibits offered to kids. A few years ago I went to an art museum in boston that had this side room filled with tables where you could color and create your own portrait. Saw a bunch of kids engaged with that rather than looking at the paintings on the wall.
For clarification, I really enjoyed the one art museum trip I went on in highschool, but enjoyed it the least out of all of my trips. I think it's harder for kids to understand and appreciate art when they are younger, especially now in such a technological based era.
I believe other field trips are more interactive for kids and therefore more interesting
It’s not very interactive
With facilities like the EcoTarium and Boston Science Museum, Art Museums don't really provide "activities" for kids like the former. At least the last time I went to the WAM, it was "observe" as the main activity. In Science Museums, kids can interact and explore with physical demos, etc.
I think some kids aren’t fully able to appreciate art at a younger age
Boring compared to the others
I believe that for younger ages, art museums won’t reach out as “fun” to many students and that they may not be able to fully understand or appreciate some of the historical meanings behind many artworks
not interactive, yelled at when acting rowdy
I couldn’t really appreciate art when I was younger, it’s something you learn to love as you mature. When I was younger, i wanted more interactive field trips like science museums. Art we would just look at if it was pretty.
Not engaging enough for young kids. More appropriate for High School.
People tend to find art "boring" and unengaging. While I don't agree with that statement I know many classmates who do. Additionally, art museums tend to be a lot less interactive than other field trips and also kids don't like being quiet, which is the norm in that sort of museum. I think that if I had gone on a field trip to one (sadly I never got to) than I would have really enjoyed it regardless of what I've said.
As a kid, I had a hard time being places where it was really quiet and mostly independent viewing/reflection. I found museums that were more interactive and louder I liked more - for example The Museum of Math.
I feel that enjoyment derived from art museums, taking in and analyzing the art, doesn't appeal to kids since kids like interactive things, big flashy things that wow them

If the art museum is interactive, yes. But overall no because most kids don’t want to just walk around and look at things if they aren’t really interested in art
Art is boring to me even as an adult (sorry), and especially as a child I mostly just liked Planetariums and monuments. I also didn't have many art/art history courses in k12 schooling so I never learned enough about it to appreciate the museums.
Modern art is fun but kids don’t want to look at similar portraits of random people for hours
They are often not engaging and for those who appreciate fine arts
Kids haven't seen the depression it takes to see that shapes can make you feel SOMETHING inside for once.
Depends what art museum, but most are stuck up and snobby. I’d rather die than look at a banana taped to the wall as a kid
Kids like to be be interactive and be active, and art museum is not the the best place for them to do that.
Art museums are not as interactive; they're for more observant people who have a genuine appreciation for art. I was a student who had a genuine appreciation for art, science, and history growing up, and I was the more observant/reserved type, so it felt more my setting. But overall I think the biggest difference is the experience. Museums, especially art museums, offer an experience that you have to try to engage with and put more effort into interpreting, whereas zoos, science centers, and aquariums try to engage with you by offering things that are constantly moving, free to touch, and even living, which doesn't require as much processing and interpretation. Though I must say, I really did enjoy the MFA's fashion exhibit back in 2016. The incorporation of technology into the pieces themselves made the pieces much more fun and even a bit interactive.
The art in art museums is almost never made by kids. It my opinion, it also presents itself as "superior" in some way due to adults having more worldly experience I guess? When I was a kid I always hated going to art museums because I couldn't relate to them or connect with the feelings the art was supposed to invoke.
Kids don't care about art - field trips should be hands on experiences for kids
It was for me but non-of my friends like it. My favorite is MoMA.
They are usually a bit "boring" for younger children. Older kids, around high school aged, I think they usually enjoy them. Especially big ones with a lot of exhibits like the Met.
They usually aren't very interactive, and their (read: my) attention span is hard to hold through a whole field trip with only visual and maybe audio exhibits
Not a fan of paintings and stuff
As a kid I never really appreciated the art in the museums, it didn't feel like I was getting anything out of the museum. Art museums also mean kids can't move around much and have to stay with their chaperones at all times, which can be hard on a kid.

Table 9-5 “If you chose ‘No’ above, please Explain.” Results