Surface Metrology Museum Exhibit

An interactive Qualifying Project Report

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

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June 1, 2014

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Special thanks to…

        Professor Chris Brown

        Surface Metrology Lab

        Ibar De La Cruz

        Randall Robinson

        Robotics Department

        Oliver Kreylos

Without your help, this project would not be the same.

1. Introduction

Surface metrology is the study of measuring and analyzing the geometry of surfaces. While this could be at any scale, in this study we are concentrating on a small-scale, 10mm or less. To measure surfaces, contact instruments (classical, mechanical stylus profilometer, atomic force microscope) or non-contact instruments (laser microscope, confocal microscope, and laser scanner) can be used. For this IQP, the Olympus LEXT OLS4000, a scanning laser confocal microscope was used. Confocal microscopes scan vertically. The purpose of these measurements is to study the surface and identify its correlation to the function, history, and/or quality of the object. However, the topic of surface measurements cannot be discussed without mentioning the importance of filtering. Errors typically result in measurements and therefore it is necessary to use filtering software to preserve the integrity of the measurement.

1.1 Objective/Exhibit Mission Statement

The objective of this IQP is to design a surface metrology museum exhibit to be displayed in the future on campus in order to help create awareness for WPI students about the topic. Another objective is to design an exhibit that merges art and science in order to increase the effectiveness of the exhibit regarding how well it engages visitors.

1.2 Rationale

In order to discuss the importance of this study, we must first decompose our objective into three topics: surface metrology, museum exhibits, and STEAM teaching, then look at the importance of each.

1.2.1 Importance of Surface Metrology

Surface metrology is used in manufacturing where the surface roughness of a machined work piece must be within certain limits to ensure proper functionality. Therefore, surface metrology is used for quality assurance (Whitehouse 1994). Recently, surface metrology has also been expanding its applications to the biomedical field. An example of this is the designing and fabrication of orthopedic implants with a "surface texture optimized for bone ingrowth application (Curodeau et al. 2000)." Surface metrology can even be applied to various other fields including, anthropology, archaeology, art conservation, biology, chemistry, all branches of engineering, food science, forensics, geography, geology, optics, physics, standardization, and tooth wear, which were discussed at the 4th International Conference on Surface Metrology in Hamburg in March 2014 (Universität Hamburg 2014).

1.2.2 Importance of Museum Exhibits

There are approximately 850 million visits each year to American museums, more than the attendance for all major league sporting events and theme parks combined (American Alliance of Museums 2013). We naturally have a hunger for more knowledge and museums cater to that hunger. In fact, museums provide knowledge in a way that most prefer (Falk 2000). "A number of investigators have found that humans are highly motivated to learn when they…have choices and control over learning (Falk 2000)." People go to museums on their own time and by their own free will, which takes the pressure or anxiety that learning in other environments may create (Falk 2000). Also, "Americans view museums as one of the most important resources for educating our children and as one of the most trustworthy sources of objective information (American Alliance of Museums 2013)." Visitors expect that they will find understandable and authentic presentations in a museum, which is why they feel so comfortable relying on exhibits as a source of learning (Alt and Shaw 1983).

In addition to that, museums are also important economically. "Museums directly contribute more than $21 billion to the national economy (American Alliance of Museums 2013). " They also employ 400,000 people in America, as well as "invest more than $2 billion a year in education (American Alliance of Museums 2013)." According to John Falk, as we "transition from an industrial to a knowledge based economy, knowledge and meaning-making more than ever become key to social and economic well-being (Falk 2000)."

1.2.3 Importance of STEAM teaching

In order to increase the effectiveness of learning science, technology, engineering, and math (STEM), teachers and administrators across the country are developing a way of teaching by incorporating art, hence (STEAM). According to Nettrice Gaskins, a media and technology expert, "Art helps engage students who are not rote learners (Krigman 2014)." Teaching through STEAM may be most effective due to the following statistics regarding learners: approximately 65 percent of the population are visual learners (Mind Tools 1994); the brain processes visual information 60,000 times faster than text (3M Corporation 2001); 90 percent of information that comes to the brain is visual (Hyerle 2000); visual aids in the classroom improve learning by up to 400 percent (3M Corporation 2001). "Collaboration, trial and error, divergent thinking skills, dynamic problem solving, and perseverance are all skills that are fostered by the arts and can be brought to bear to improve STEM learning," U.S. Representative Aaron Schock says (Krigman 2014). "Arts education and integration are essential to producing a future workforce with the skills employers are looking for (Krigman 2014)."

STEAM teaching is valuable economically while America is looking to innovation to provide a prosperous future. Although innovation "remains tightly coupled with Science, Technology, Engineering and Math, …Art [and] Design are poised to transform our economy in the 21st century just as science and technology did in the last century (STEM to STEAM 2014)."

1.3 State-of-the-Art

1.3.1 Museum Exhibit Design: merging art and science

1.3.1.1 *Interactive Museum*

In 2012 and 2013, the IQP *Interactive Museum* was done on developing "museum and exhibit ideas for WPI… [To] generate awareness and excitement to students, faculty, and visitors through interactive and involved concepts," as well as designing "attention-grabbing installations for presentation to the Worcester Art Museum (Fernandez et al. 2013)." They wanted to create a marriage between art and technology. This IQP also involved conducting research on exhibit design. Their research determined that if the concept is too complicated, it will deter visitors, but if it is not in-depth enough, it will also not hold the attention of knowledgeable visitors. This required the group to design an interactive exhibit for WPI that was not too simple for college students, but also included interactivity that did not take too long to execute.

1.3.2 Merging Art and Science

1.3.2.1 Lab School of Washington

The Lab School of Washington in Washington, D.C. integrates art and science to help teach students with language-based disabilities. According to article author Rebecca Alberts, "Art and science are intrinsically linked… Both artists and scientists work in a systematic but creative way… In the classroom, integrating science and visual art can provide students with the latitude to think, discover, and make connections (Alberts 2008)".

1.3.2.2 *Applications of Surface Metrology to Issue in Art*

Applications of Surface Metrology to Issues in Art is an IQP conducted in 2008 that took the science of surface metrology and uses it for the following art applications: restoration, preservation, and identification. A portion of this project included taking measurements in the WPI Surface Metrology Lab of the paintings provided by the Worcester Art Museum.

1.3.3 Specific Exhibits

1.3.3.1 Augmented Reality Sandbox

Oliver Kreylos of UC Davis created an "Augmented Reality Sandbox" using a Microsoft Kinect 3D camera, sandbox software he created, a data projector, and sand. He also provides specific instructions on how to replicate the sandbox he designed on his website (Kreylos 2014).

The Museum of Science in Boston also had their version of the sandbox with their "sandscape" exhibition. This exhibition started with using sand and by the end, attempted using rice.

Further information on these projects and others can be found in Appendix B.

1.3.3.2 Ellen Schulz Zebra Tooth 3D Print

In 2006, Dr. Ellen Schulz (2006) of the Zoological Museum in Hamburg studied zebra tooth wear for her paper, "Tooth wear gradients in zebra as an environmental proxy - A pilot study." She made a 3D

print of the tooth surface measurement and used the physical model as a teaching tool for museum visitors.

1.3.3.3 Art.Science.Gallery

Art.Science.Gallery is one of the first art galleries in the nation to solely display science-related artwork. "The gallery strives to make science more accessible through visual arts (Torres 2014)." The venue allows people of various backgrounds can learn and appreciate both art and science. The gallery's mission statement is as follows:

> Our mission is to provide a friendly environment to make science more accessible to everyone through science-related visual arts exhibitions, foster the careers of emerging and established artist-scientists and to provide professional development opportunities for scientists to become more engaging public communicators (Torres 2014).

1.3.3.4 Olympus BioScapes International Digital Imaging Competition

For the past decade, the Olympus Bioscapes Digital Imaging Competition has been held annually by the Olympus Corporation of America. Contestants enter with images of life science they have measured using Olympus' microscopes, which portray "the beauty, power and importance of science (Olympus Corporation of the Americas 2014)."

1.3.3.5 Virtual Urchin

Virtual Urchin is an open access website created by Stanford University educators, which provides multiple interactive tutorials including: fertilization & development, microscope measurement, anatomy, predator & prey, microscope compare, specimen compare, our acidifying ocean, embryo microinjection, and embryogenesis to hatching (Stanford University 2013).

1.4 Approach

1.4.1 Museum Exhibit Design

Similar to the *Interactive Museum* IQP, we are designing an exhibit to be put on campus. The difference is that they are solely focusing on an interactive exhibit. For ours, we will be doing a combination of interactive and static displays. Of course the topic of the exhibits will be different. Ours focuses on different aspects of surface metrology and its applications.

1.4.2 Merging Art and Science

Similarly to the projects mentioned in Section 1.3.2, we are merging art and science for our museum exhibit. We are not necessarily using art to explain surface metrology, but using surface measurements and displaying them as art. This exhibit is explained further in Section 1.4.3.2.

1.4.3 Specific Exhibits

1.4.3.1 Augmented Reality Ricebox

Similar to Monobanda's and Oliver Kreylos' vision to see their sandboxes in museums (Appendix B), we also believe that adding an Augmented Reality Ricebox will enrich our surface metrology exhibit.

The primary purpose of creating the UC Davis sandbox was "to teach earth science concepts… [And] how to read a topography map, the meaning of contour lines, watersheds, catchment areas, levees, etc. (Kreylos 2014)." The purpose of our ricebox is to teach surface metrology concepts. A topographical map uses different colored contour lines to show different elevations and features of land. Similarly, software analysis/imaging software shows the topography of the surface of an object after measurement. The ricebox uses the basic concepts of surface metrology if you think of the rice as an object and the Kinect camera is measuring the surface then displaying the topography onto itself.

Although rice created a mess with the exhibit at the Boston Museum of Science, we still chose to design our project with sand since most of the mess was due to children visiting the exhibit. Economically, a bag of rice is more affordable to purchase than the white modeling sand recommended on the website, and therefore is ideal for a project on a small budget.

For our ricebox design, we also collaborated with physics teaching assistant at WPI, Ibar De La Cruz, in order to build the prototype. Ibar, who is currently working towards his PhD, has his own uses for the Augmented Reality Sandbox design. For his research, he uses a plow to drag granular material and his interest is in the shape of the pile dragged by the plow as seen in a reference frame where the plow is at rest. Instead of rice or sand, he is using glass beads (granular material) in its place. The setup with the camera and sand box software will be used to measure the shape of the pile dragged by a plow. In his thesis he is proposing that the pile has a characteristic shape that is based on the geometry of the plow (horizontal width and immersion depth) and the granular material's angle of repose and packing. The setup allows him to digitize the shape of the pile by sketching its level curves. As a result he would have a digital shape of the upper boundary surface. The reason for using the granular beads is due to their consistent diameter which minimizes effects that cannot be attributed to the randomness of the shape of the grains.

1.4.3.2 3D Printed Surface Cabinets

Just as Ellen Schulz used her 3D printed surface as a teaching tool at the Zoological museum, we designed an exhibit that uses 3D printed surfaces as the door for cabinets. Inside the cabinet is more information on the functionality of the surface in addition to the object the measurement was taken from (Figure 1).
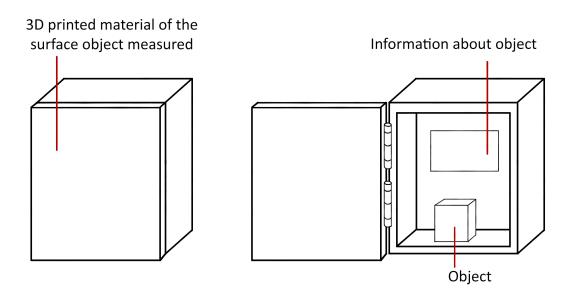
3D printed material of the surface object measured

Information about object

Object

Figure 1 3D Printed Surface Cabinet

1.4.3.2 Surface Measurement Art Gallery

Similar to the Art.Science.Gallery, our Surface Measurement Art Gallery displays science-related artwork with the hope of engaging a larger audience that includes those who may grasp concepts better with visual arts. Our gallery, however, solely focuses on surface science artwork, whereas Art.Science.Gallery does not focus on a specific science.

Our gallery is similar to Olympus' competition (Section 1.3.3.4) in that both involve taking microscope measurements to produce the artwork. The difference is that the Olympus competition is taking image measurements rather than surface measurements. The artwork in their case is the image underneath the microscope whereas the artwork in our gallery is the topographical representation of the objects' surfaces.
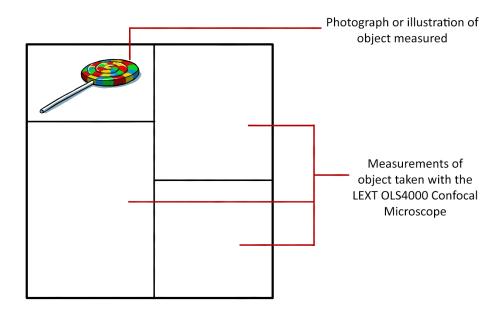

Figure 2 Layout of Surface Measurement Collage

1.4.3.2 Virtual Microscope and Surface Measuring Tutorial

Similar to Virtual Urchin's interactive tutorials, this interactive exhibit is a computer tutorial where visitors learn how to take microscope measurements. Virtual Urchin also has many other interactive tutorials (Section 1.3.3.5), but our tutorial focuses solely on the surface measurement of an object.

2. Method

2.1 Designing Exhibits

2.1.1 Creating museum exhibits

"The introduction of technology into museums and exhibitions is a difficult and delicate matter (Ciolfi and Bannon 2002)." To learn how to do this we conducted research on designing an engaging exhibit to bring more awareness to the topic of surface metrology.

Sue Allen, the founding director of the museum of science, art, and human perspective Exploratorium, goes into more detail about the ideal characteristics and wrote a paper based on her experience as the director on the ideal qualities of an exhibit for visitors to learn without the use of a guide or staff member (Allen 2004). Museums are appealing alternative to learning compared to classroom education because they provide choice, hands on interactivity, and stimulation. However, because there is the freedom of choice to visit a museum it is important to engage visitors at all times (Allen 2004). In her paper, she goes into detail about four general exhibit qualities that help and motivate visitors to learn: immediate apprehensibility, physical interactivity, conceptual coherence, and diversity of learners (Allen 2004).

2.1.2 Taking surface measurements

With the help of the Surface Metrology Lab on campus, we learned how to take surface measurements using the Olympus LEXT OLS4000. For most of our measurements we did not use greater than a 20X lens. For learning purposes, we first took measurements of miscellaneous objects we found, such as, a rubber band, tape, and an eraser. When we became more comfortable with using the LEXT we focused on making measurements of different candies. The measurements are shown in Appendix D.

2.1.3 Making prototypes and specific exhibit design

2.1.3.1 3-D Printed Surface Cabinets

After taking surface measurements, we looked into how to print the surface as a 3D model. The measurement file in MountainsMap has to be converted to an STL file, which most rapid prototyping companies require in order to print the object measured.

We attempted to get a quote for a candy surface we measured- a pink dot from quickparts.com and solidconcepts.com, however the file was too large to receive a quote. The recommended size for instant quotes are 25MB or smaller and ours was over 140MB. To solve this, we had to simplify the surface in MountainsMap to where we reduced the number of points measured from the surface until it was a lesser complex surface that could actually be manufactured by a 3D printer. We also realized that we needed to find a different 3D printing company that did multicolor in a gradient style similar to a topography map. For this we went to Sculpteo's website (Figure 3). The largest scale we could choose for this part was 12.5 times larger than the original size of our model (0.639 cm x 0.639 cm x 0.144 cm) which means the printed part will be 7.992 cm x 7.992 cm x 1.800 cm. This size is much smaller than we originally intended for the 3D printed part, which we envisioned being closer to 30 cm long and wide. If we increase the scale greater than 12.5, the dimensions exceed the maximum dimensions for the wax

material. The other problem we encounter is with price. For this size, the cost is $107. This could be a problem for an exhibit on a budget, where we were planning on printing multiple measured surfaces.
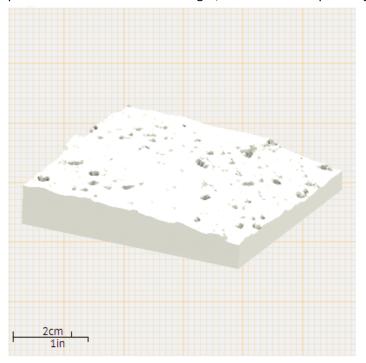
2.1.3.2 Surface Measurement Art Gallery

This would be considered under the category of digital art. Although digital art has been under some criticism as whether it should actually be considered art, in our opinion it is becoming increasingly more accepted. Similar to a paint brush or pencil, "the computer is simply a tool, one that offers artists new resources and opportunities for reaching the public… (Jenkins 2002)." With WPI being a school focused on technology, we believe that using digital art will be an effective way to capture the interest of engineering students who may pass by a surface metrology exhibit on campus, especially since there are courses offered at WPI for digital art. For the future, it may also be interesting to work with the Interactive Media and Game Design Department and see how surface measurements can be tied to the course AR 1101 (Digital Imaging and Computer Art).

"Uncovering the secrets and discovering the precious hidden content is perceived as very rewarding by the visitors" and therefore we designed another exhibit that uses this "cabinets of curiosities" concept to engage visitors (Ciolfi and Bannon 2002). Mini-cabinets could be spaced on different walls of the exhibit. The door of the cabinet would be a multi-colored 3D printed surface. When you open the door, inside are the object and a description of how the surface relates to the function of the object. For example, the door of the cabinet could be the 3d printed surface of a gummy bear. The visitor is able to discover what the surface is which is more rewarding than having it already displayed underneath a picture of the surface. Inside would be the gummy bear and more information about the surface such as the fact that they receive a coating of beeswax and carnauba wax in order to give them shininess as well as to prevent them from sticking together (Haribo of America, Inc. 2014).

2.1.3.3 Virtual Microscope Design and Prototype

This exhibit consists of several computer stations where visitors can go through a tutorial on how to make surface measurements using the Olympus LEXT microscope. Using a computer rather than the real microscope reduces costs and risk of damaging equipment. We believe that this exhibition will cater to visitors' desire for "layers of activity (Ciolfi and Bannon 2002)." This exhibit is meant as an introduction to the subject of surface measurement and if students have further interests they can then join the Surface Metrology Lab and use the real LEXT microscope.

For the design of this exhibit, we first built a prototype of the tutorial. Pictures were taken at each step of the measurement process for an Elkay sink surface sample. These pictures were then used in Microsoft PowerPoint to make the presentation. Some slides are given a timer while others move forward when the "Action" button is clicked on.

2.1.3.4 Augmented Reality Rice-box

To create our version of the Augmented Reality Sandbox, we used the instructions provided on the UC Davis website created by Oliver Kreylos, a professor at that university. On the website is the list of materials needed to build an Augmented Reality Sandbox. Those materials are: a computer with a good graphics card running any version of Linux, a Microsoft Kinect 3D camera, the free downloadable software for running the sandbox program, a digital data projector, a sandbox, and the sand (rice).

There was virtually no budget for this project therefore we obtained as many materials as possible from resources available to us at WPI. The computer was provided by WPI's Computer Operations Manager Randy Robinson. With the help of Ibar De La Cruz, Ubuntu Linux and the sandbox program was able to be installed on the computer. Also, with the generosity of the WPI Robotics Department, we were donated a Microsoft Kinect 3D camera. For D-Term only we were allowed to rent a projector from WPI's Academic Technology Center. The materials we did purchase were a bag of rice and a box. The bag of rice is 25 lbs. and the box has the dimensions of 27 x 17 x 12 in.

Building a prototype was a collaborative effort with Ibar De la Cruz (Section 1.4.3.1). Although the prototype uses granular beads, as mentioned before we designed our exhibit to use rice. The dimensions of the box holding the glass beads are 13 x 4.5 x 23.5 in.

Figure 4 The computer set up

The process of building the sandbox required us to learn how to use the software and equipment involved with it. With the help of De la Cruz, we learned how to use a Linux computer, the terminal coding, and the various other programs involved to run this sandbox project.

Figure 5 Close up of Microsoft Kinect 3D camera

Using metal bars and clamps, the Kinect was set up to be directly above the box as instructed on the UC Davis site. The metal bars allow the height of the Kinect from the box to be adjusted.

For this first prototype, we decided to not set up the projector since it is not needed to calibrate the Kinect, is not necessary equipment for the sandbox to function.

Internal calibration of the Kinect was done before setting up the Kinect and has to be done only once. However, the extrinsic calibration of the Kinect, which is done when the Kinect is in place, has to be done repeatedly if the Kinect is moved.
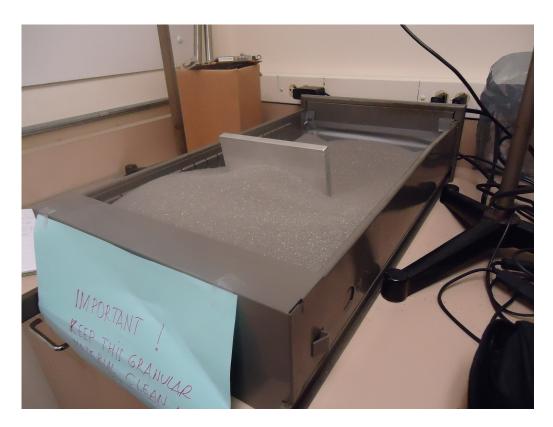
Figure 7 Close up of the box with glass beads

Figure 8 Close up the box with glass beads at a different angle

Figure 7 and Figure 8 shows that the level of the glass beads is not a completely flat surface. Touching the glass beads directly with hands is not recommended since the beads are very small and can stick to hands if the hands are not dry so a metal slate is used to adjust the levels of the glass beads and keep a portion of them in place. In order to test whether the Kinect was properly calibrated, the level of the glass beads remained unchanged and the height of the camera was adjusted. This ensures that the only factor affecting the Kinect's video feed is the height of the camera and not because of any changes made to the level of the glass beads.
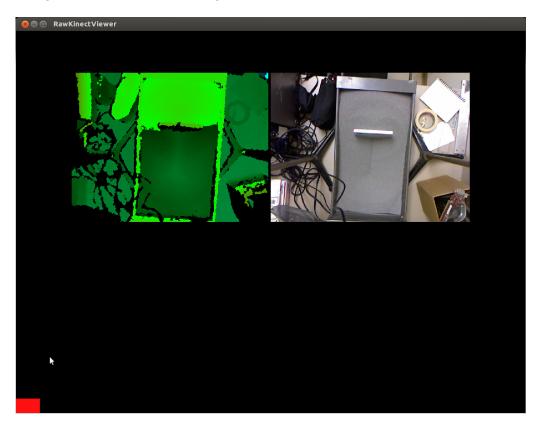
Figure 9 RawKinectView

In Figure 9, the Kinect is set at a height of about 31 in. away from the box. The Kinect Is able to record the changes of the glass bead's surface topography to a small degree from that distance, as shown on the computer monitor. Figure 9 shows the video feed of the Kinect set up from Figure 6. The image on the right is normal video feed of the sandbox and its surroundings and the image on the left is the topography feed of the sandbox and its surroundings. The topography of the glass beads is being recorded, but the level of topography is not shown in great detail.

The UC Davis site instructions recommended a box size of 40 X 30 in. with the Kinect located above the box at the height of 40 in. and facing the surface of the contents of the box orthogonally. The height of the Kinect from the box corresponds with the length of the box while the resolution and quality of the Kinect camera feed corresponds to the height of the Kinect from the box. Changing the size of the box requires adjusting the height of the Kinect camera by the same factor that the size of the box was changed.

The recommended box size is close to square shaped in dimensions rather than the rectangle shaped box that is being used to hold the glass beads. This most likely had an effect on the quality and resolution of the Kinect camera since the field-of-view of the Kinect does not line up with the target area (the box). The calibration of the Kinect can be customized to fit the target area more precisely but even with the calibration the ratio of the Kinect camera's height from the box and the box's length itself would have to be adjusted accordingly to get a more precise topography reading. For the box we were planning to use for our exhibit, we planned to cordon off sections of the box so the target area for the Kinect would have the dimensions of 20 x 15 in. and the Kinect's height from the box would be adjusted accordingly to 20 in. above the box. The ratio of the target area would still match up with the ratio of the recommended box size and the smaller size would take up less space in the potential exhibit area.

Figure 10 The sandbox with the Kinect at an adjusted height

In Figure 10, the Kinect's height from the sandbox has been adjusted to the height of 23 in., the same length as the box of glass beads. Adjusting the height of the Kinect so it is closer to the box has caused the Kinect to record the topography of the glass beads in the box in greater detail. Moving the Kinect too close or too far from the box will cause the box to be misaligned with the Kinect's field-of-view. As stated on the UC Davis site, "The size of the sandbox is limited by the Kinect camera's minimum and maximum sensing distances, and the desired sandbox resolution. Due to the Kinect camera's approximately 90° field-of-view, the Kinect camera has to be mounted about as high above the sand surface as the sandbox is wide (Kreylos 2014)".
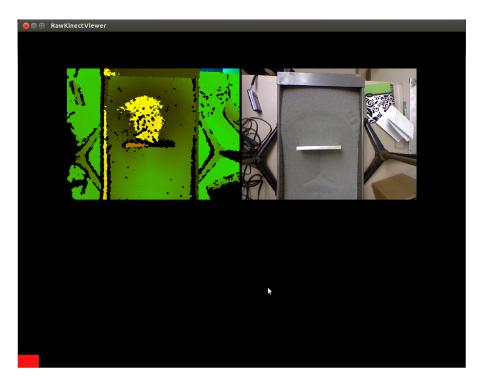
Figure 11 RawKinectView

Figure 11 is the video feed of the Kinect set up from Figure 10. The topographical video of the box with glass beads in Figure 11 has more colors than the topographical video feed in Figure 9, which only featured green and dark green. The brighter colors shows that the Kinect is picking up the topographical levels of the glass beads on a more detailed now that it has been moved closer to the box. However, as it can be seen in Figure 11, the topographical feed is not perfect. There is extra noise (the black spots) in the topographical feed of the box, meaning that although the Kinect and the programs are functioning and have been calibrated, the set up as a whole is not working as accurately as it could be.

3. Results

3.1 Assessing the Quality of Exhibits

Usually, evaluating the worth of an exhibit cannot be done by the creator of the exhibit just looking at their creation; the opinions of other people are needed. "Success of an exhibit can be judged in two ways—visitor measures and/or critical appraisal by experts. Visitor measures include behavior, knowledge, and affect. Critical appraisal by experts can take any of three perspectives— that of the expert in visitor studies, that of the expert in the subject matter [and] that of the artist" (Bitgood 1994). Because we are only in the design stages of the project, we are only able to evaluate the quality of design.

We used Robert L. Russell's "The Top Ten Points for Designing Engaging Exhibits" in order to self-evaluate the quality of our exhibit designs. More in-depth information about Russell's top ten points can be found in Appendix E. From our self-evaluation we learned that our exhibit design is moderately sufficient at providing advance organizers, as well as designing involving exhibits. Our exhibits are also designed to be easy to use and meet the criteria of presenting real objects/phenomena. The aspects of design that we need to work on are providing entry points for meeting our visitors' needs, in addition to offering visitors' feedback and choices. What we did do well at is design exhibits that offer a way for cooperative engagement, especially in the ricebox and gallery exhibits. One of the things we could not yet evaluate was whether or not we met visitors' expectations (Russell 2000).

4. Discussion

4.1 Time issues

One of the problems we have had during this project is managing our time well. Especially towards the beginning of the project, we did not spend an appropriate amount of time on the right things. We also did not spend enough time meeting with each other. The times that we did meet, also could have been more productive. Together we would go and ask someone a question, which only one of us could have gone and done alone. Instead we should have spent that time together to complete tasks that could not have been done alone. For example, making decisions about directions for our project to go and making the outline for our paper.

At times we did not make full use of our Gantt chart and what it represents. We have learned to try to be more specific in our Gantt charts about tasks and their due dates so that we have more of a plan. Knowing the due dates of specific tasks also would have also given us more direction since we would always have some sort of end goal. Throughout this project it did feel as though we had no sense of direction and it made it difficult to focus on exactly what needed to get done. Actually, one of the reasons why we felt it was difficult to focus on tasks was because our project ideas were changing so much. We should have not changed our course so much after mid B-Term because without finally deciding what our project was going to be, we put effort into one project idea, but then ended going into another direction anyways.

Although we initially wanted to actually build an exhibit to be put on campus, there was not enough preparation time spent in order to reserve an area on campus and make a good exhibit. When we inquired to the WPI library whether we would be able to make an exhibit there, we were told that people usually reserve a space in the library a year in advance. We were told however that we could have a space in C and D Term, however they needed to know specifics about the exhibit we were planning on building and at the time we were just starting the project and so we did not clear answers. Building a really good exhibit really takes a lot of time because there is so much planning involved and resources have to be gathered for building it, which takes even more time when you are trying to build an exhibit on a small budget.

4.2 Money Constraints

At the beginning of A-Term, we imagined this project would be actually built. Although it is what we hoped for, we encountered difficulties when building the exhibits cost more money than we had available. For most of it we tried to be as resourceful as possible. This meant finding as many things that we could borrow from the school or get donated from different organizations. When it came to the sandbox we were able to get most materials for free. Unfortunately, the 3D printed cabinet doors were going to be quite expensive and therefore this time around we were not able to purchase them. In the future, however, it would be wise to start earlier in the project looking for donations for organizations and companies that may benefit from our project.

4.3 Planning an Exhibit

If we had the opportunity to plan and create an exhibit, whether it be for continuing this project for creating an exhibit about surface metrology or a new exhibit altogether, there are plenty of things we would do differently.

As addressed before in section 4.1, a problem we faced during this IQP was the lack of a single, clear goal to accomplish. Over the course of the IQP's terms, we had many changes in our objective and our planning. The revisions of our IQP's objective are shown in Appendix A. For future exhibits, we would prevent this problem by establishing a clear goal and objective as soon as possible. Our objective and plans have to remain flexible since they will be revised in order to compromise with the exhibit host's criteria for exhibits, but having a solid understanding of what we want to do is essential.

After deciding on our objective and plan, what the exhibit is going to be about, and where we would like it to be hosted, the next and most important step in the exhibit planning process is to establish contact with the appropriate people in advance. Establishing contact early on with the exhibit coordinators of the location where we want the exhibit to be held will help clear up on what we need to do early on. We will learn from the exhibit coordinators what are the specific requirements needed for the exhibit, what can be provided by the exhibit host such as cabinets or technical equipment, how much space is available, how much space we plan on taking up, how long the exhibit will be held, any security measures needed, and etc. With that knowledge in mind, we can begin the process of planning out the exhibit and seeing what is within our scope. This step would have to take place at least a year or more prior to actually building and displaying the exhibit and will have an impact on the initial objective and plan that was established prior to contacting people. It is important that not only we have the time to afford to make revisions in our plan but also for the people we have contact with to have the time to respond to our questions.

Along with establishing contact with people early on, we would also consider having a larger number of people working with us to design and create the exhibit. This IQP consists of only two people and, while it is possible for just two people to design and create an exhibit, a fair number of people are needed to design and create a high quality exhibit. In the handbook called *The Field Guide for Museums*, the writers recommend that it would be "helpful to recruit a balanced board whose talents can provide your museum with access to useful services and who reflect the constituency you serve" (Bailey et al. 2004). For example, the same handbook lists people such as attorneys, educators, certified public

accountants, local historians, business leaders, representatives of the geographical region, bankers, and special audience representative as people that may be important to have in a board of trustees.

It is also important that we establish a budget before contacting the exhibit coordinators so we can discuss with them about it. As discussed in section 4.3, money issues is another problem we faced since we had virtually no budget for this IQP. For future exhibit planning, the budget issue should be one of the first problems we address early. The budget should also be discussed with the people we have made contact with to see if there are ways or areas where we can be cost effective.

While we did design some exhibits during this IQP, our time management skills lead to those designs being made very late in the IQP's term. For a future exhibit, we would like to have gotten potential designs of the exhibit done before establishing contact with the appropriate people. That way we can show them what we had in mind for our exhibit and from there we can make adjustments to the designs.

Above all else, the most essential step to these steps in preparing a future exhibit is time management. As mentioned in section 4.1, we had many issues with time management. The lack of a clear goal, schedule, and what is needed in the exhibit prevented us from effectively using our time to get out of the planning and designing stage and into the building stage of the exhibit. If we were to plan and actually build an exhibit in the future, we would need to use Gantt charts and detailed schedules more effectively.

4.4 Organizing the paper

One of the biggest problems we faced when writing the final paper is organization. It soon became evident that we, as partners, were not on the same page when it came to a common theme throughout the paper. This caused the paper to look loose and not consistent. Although we were working from the same outline, the paper lacked a common theme throughout. In order to solve this problem, we conducted a theme-decomposition for our paper, which can be found in Appendix 7.7.

7. Appendices

7.1 Appendix A: Past project ideas, objectives, and revisions

The following describe revisions made throughout the course of this IQP.

The first plan we had to accomplish the objective was to spread awareness of surface metrology to the public people by designing and building an exhibit about surface metrology and its applications to be displayed in the Worcester Art Museum. This initial plan would involve a large demographic. Since we had planned to have our exhibit displayed in a museum, we did research on what were the objectives of museums in the first place. If a museum would consider accepting and displaying an exhibit, the exhibit would have to be relevant to the state mission of the museum. Since we have little experience with creating an exhibit, we initially intended for a sample exhibit of what we wanted to display in the Worcester Art Museum to be displayed somewhere on the WPI campus, preferably on the third floor of WPI's Gordon Library. The trial run of the prototype exhibit would help us observe people's interaction

with the exhibit and learn what improvements can be made for the exhibit for the museum. The prototype exhibit would also help the curators of Worcester Art Museum judge the quality of our exhibit and decide if they would like our exhibit to be displayed at the museum.

The process of planning and creating the sample exhibit for the library led us to revise our plans so accomplishing the objective would be more possible within our time limits and budget. The plans were altered so that instead of designing and creating an exhibit about surface metrology and its applications intended for the Worcester Art Museum we would design and create an exhibit intended for the Gordon Library. The exhibition requirements and processing for Gordon Library are less stringent, formal, and time consuming compared to the exhibition requirements and processing for the Worcester Art Museum. Other advantages to holding the exhibit in the library are that there is a higher chance of the library accepting and displaying our exhibit and that it is easier to access the displayed exhibit on a regular basis than if was displayed at the Worcester Art Museum. The close proximity would allow for maintenance of the exhibit on a regular basis to be done and it would allow easier time to observe the interactions of people with the exhibits.

With the location of where the exhibit will be displayed changed, we had to learn the specific requirements needed for an exhibit to be held at the Gordon Library. We spoke to Kathy Markees, the preservation librarian who is also in charge of any exhibitions to be held at the Gordon library. For an exhibit to be held at the Gordon Library, it is necessary for the library staff to know how much space the exhibit will take up, the materials and equipment needed, the duration of the exhibit will be held at the library, and any security measures that need to be taken. Also required for a library exhibit is for any posters or images to be hung on the wall need to be framed and that cabinets or display cases can be borrowed from the library but they need to know for how long will the equipment will be borrowed, the size, and the amount. For technologic equipment, we would have to ask the Academic Technology Center to borrow equipment or set up Internet access for us if we needed it. Markees also told us that, for the most part, the nature of the exhibitions on display on the library floor we would have liked to display our exhibit was mostly artistic rather than scientific like the exhibition we planned to create about surface metrology. This gave us the idea of changing the nature of our exhibit. Instead of an exhibit that would provide only information about surface metrology and its applications, we thought that it would be more interesting and catch people's attention more if we could also combine art and science together and somehow use surface metrology to make an art exhibit.

This revision brought some changes to the objective and how we intended to fulfill it. The objective still involved us spreading awareness of surface metrology but it was also slightly altered to include showing the artistic merits of the surface metrology as a way of linking art and science together. The exhibit we planned to create would be an exhibit showing the artistic merits and abilities of surface metrology and its technology and set it up on the third floor of the Gordon Library. For this, we would have to create exhibits that could be considered artistic and were created by surface metrology technology. As mentioned in the method section, we learned to use the LEXT OLS4000 confocal microscope located in the Surface Metrology lab at Washburn Shops at building of WPI with the help of the members of the surface metrology lab. By measuring the surfaces of the various objects we would use the measurements as the material to create art.

We had also considered the thought of holding a contest with the winning contest entries being displayed in our exhibit. In order to host and spread word about the contest, we would create a website where people can see the rules for the contest and submit their entries. The main objective of this contest was that people would measure the surfaces of any object they like and they would depict their measurements in a way to make the measurements look like artwork. We would accept these files for entries: .png, .jpg, data file, 3D printed object made of any material, and video. Also allowed was editing of the measurements in order to make it look more artistic. For submitting the entries, contestants would need to provide their name, the object that was measured, and the device used to make the measurement. The entries would be judged on three different categories: technical interests, aesthetics, and level of interactivity. The judges for the contest would consist of people who have a degree of experience and knowledge with surface metrology technology and measurements or art. There would be a winner for each category and runner-ups with all of the entries submitted shown on the website. The winning and runner-up entries would be displayed at our exhibit. Along with having their entries displayed at our exhibit we also planned on giving them other prizes like money or a free trip to somewhere, possibly to WPI where they can see their entry displayed. Unfortunately there was not enough time, resources, or funding to hold a contest. The budget for this IQP is limited so we would not be able to afford to give away any worthwhile prizes to the winners of the contest. There is also the fact that a considerable amount of time is needed to hold a contest. The contestants would need time to create their entries and the judges would need time to judge the entries. It would most likely take several months if we wanted to receive high quality entries for our contest.

With creating art from surface measurements being a slight issue and the limitations and restrictions set for a library exhibit, we decided to change the location of our possible exhibit yet again from the Gordon Library to the Washburn Shops building, which is the current plan and main objective for this IQP. The Surface Metrology lab is at Washburn building so creating and placing an exhibit there would provide access to visitors to the lab to see the equipment there that we could not bring over to the library. There is also no need to fill in a certain set of space like we had to do with the library so our exhibits can be a bit more flexible in terms of size, arrangement, and material of the exhibits. Another advantage to having the exhibition at the Washburn building is that there is plenty of additional resources and information about the field of surface metrology available to the visitors if they wish to learn more about the topic since the Surface Metrology lab and Professor Brown's (a professor for this field) office are located in the building.

The time restraints and the effort of creating an exhibit had lead us to changing the objective of this IQP to only designing an exhibit instead of actually building one. Planning and building an exhibit requires at least a year or more of preparation. Considering that we have limited time for this IQP we decided to only design the exhibit. If another group is interested in our exhibit designs they can try to build our exhibit.

7.2 Appendix B: Annotative Bibliography of Augmented Reality Sandbox

An "Augmented Reality Sandbox" is a "hands-on exhibit combining a real sandbox, and virtual topography and water created using a closed loop of a Microsoft Kinect 3D camera, powerful simulation

and visualization software, and a data projector [allowing] users to create topography models by shaping real sand, which is then augmented in real time by an elevation color map, topographic contour lines, and simulated water (Kreylos 2014)."

Monobanda, a game development company, developed Mimicry, a game that uses a physical sandbox and digital landscape. People put their hands into the sand to create sculpt a terrain for digital players to race through with a digital ball. Monobanda's purpose is to "enrich museums, festivals, businesses, and exhibitions with their projects, since games provide a strong bond between views, the location, and the message (Monobanda 2014)". When visiting the official Mimicry website, it says that the project is still under development.

On November 28, 2011 a group of Czech researchers uploaded a video on YouTube, "Interaktivní "Kinect" pískoviště (sandbox)." This sandbox is similar to the idea of Project Mimicry by projecting digital topography over physical sand. In August 2013, Oliver Kreylos, a professor at University of California, Davis, commented on the youtube video "You can download sandbox software and build the rest yourself, Google 'AR Sandbox' and follow the first link (Kreylos 2013)." If you follow the link, Kreylos provides sandbox installation instructions and more in depth information on the "Augmented Reality Sandbox." Kreylos' project goal was to create a final product that was "self-contained to the point where it can be used as a hands-on exhibit in science museums with little supervision (Kreylos 2014)."

Other groups have also built an augmented reality sandbox, including Will Fisher and Greg Wirth from University of Alaska's Geographic Information Network of Alaska. They used the free downloadable software that Kreylos provides to create their own version. "Fisher and Wirth said they also hope to polish the user interface for the program so they can help make it available to any teachers or parents or interested sandbox owners who want to create their own augmented-reality sandbox (Morrow 2014)."

The Museum of Science in Boston had their "sandscape" exhibit located in Cahners Computerplace. After inquiring with Janna Doherty, Discovery Center Coordinator for more information about their version of the sandbox, we learned that it was discontinued for a few reasons. One, the components and technology were on temporary loan from MIT, so it was returned to the university last fall. Two, the Cahners staff is currently re-envisioning their entire exhibit and likely taking it into a new direction. Three, the technology was outdated at this point; the Kinect camera is a newer and more improved technology for this kind of project. Four, children visiting the exhibit were making a mess out of the sand, and therefore they changed to rice. The rice actually made a more visible mess but the visibility helped make cleaning it up easier.

7.3 Appendix C: Further Details of Specific Exhibits

7.3.1 Virtual Microscope Tutorial

The following is the prototype of the Virtual Microscope Tutorial, which consists of 47 slides. This prototype is just an example of bringing a visitor through the process of measuring the surface of Elkay made kitchen sink. Through the tutorial, the visitor will learn how to use the Olympus LEXT microscope used for measuring in the WPI Surface Metrology Lab.

Today you will be measuring the surface of a kitchen sink.

Elkay Crosstown Stainless Steel sinks

We are going to make a surface measurement using the Olympus LEXT microscope shown on the left.

Click the surface to place it on the microscope plate.
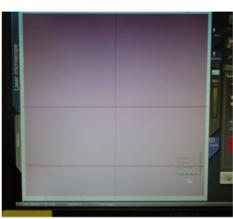
The blue dot shown on the sink surface shows that the microscope is on and ready to take a measurement.

FIRST we need to move the microscope closer to the surface using the knobs on the side.

Click the knob until the surface on the screen is in focus.
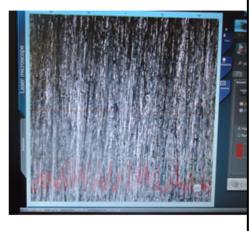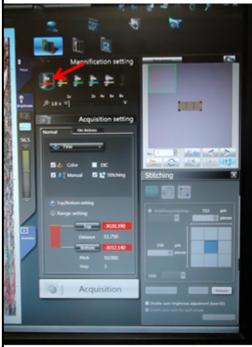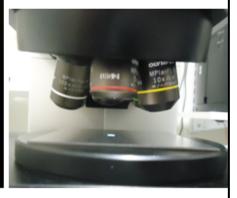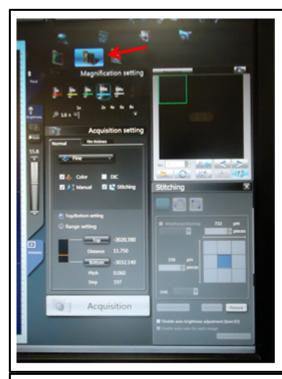
The microscope is in focus and at the right height.
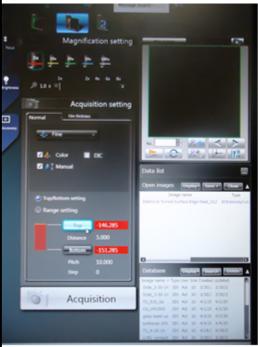
Notice right now we are on the 5X
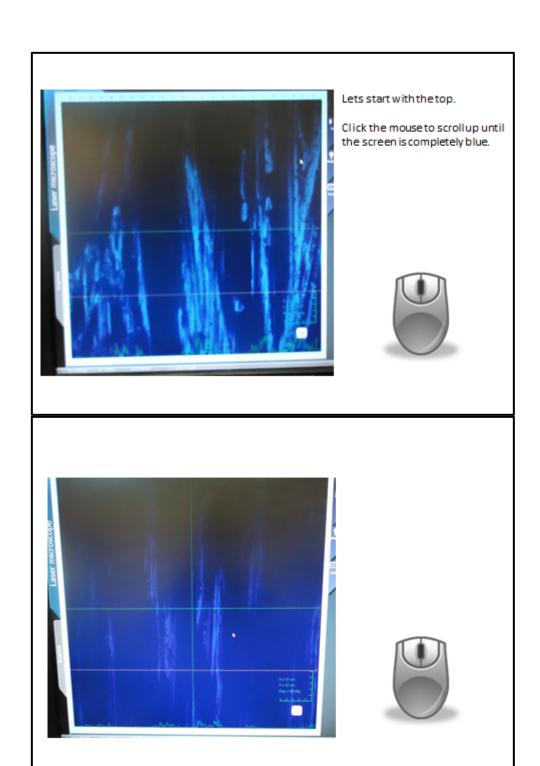
Click the "laser" tab. This makes it easier to see the points of the surface.
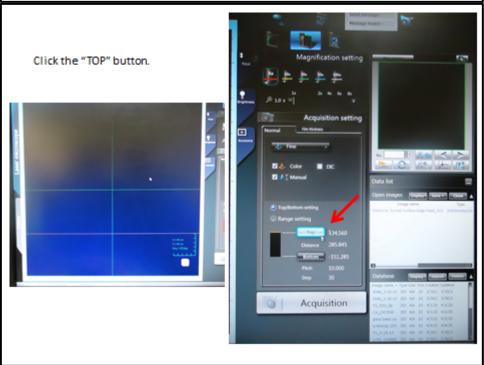
We need to define the "TOP and "BOTTOM" before we move on to other magnifications.
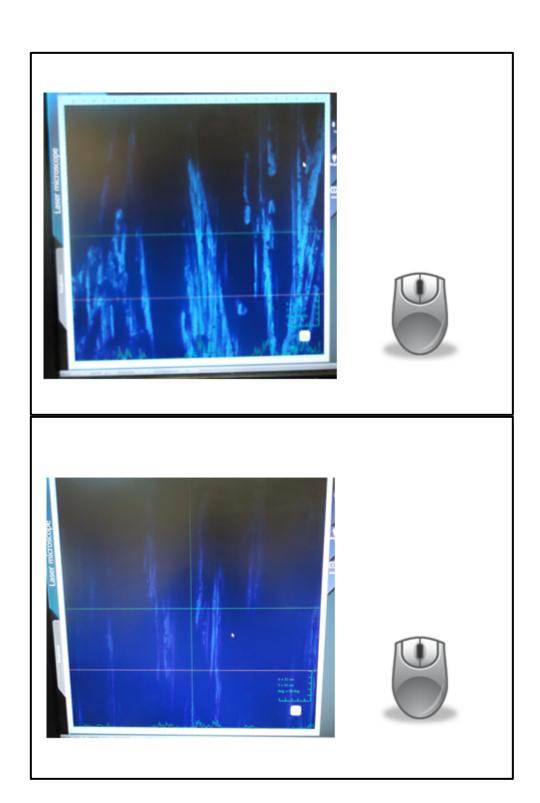
Defining these lets us know our highest and lowest point.

Lets start with the top.

Click the mouse to scroll up until the screen is completely blue.

Click the "TOP" button.

To define the BOTTOM, click the mouse to scroll down until the screen is completely blue again.

Now we are at the bottom.

Click the BOTTOM button.

Top/Bottom setting
Range setting

Top   134.560
Distance   280.000
Bottom   -145.440
Pitch   10.000
Step   29
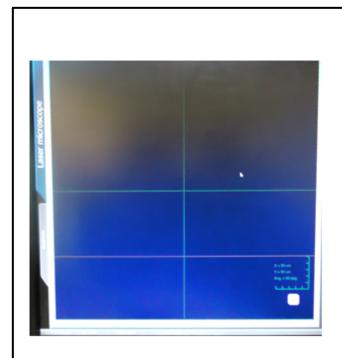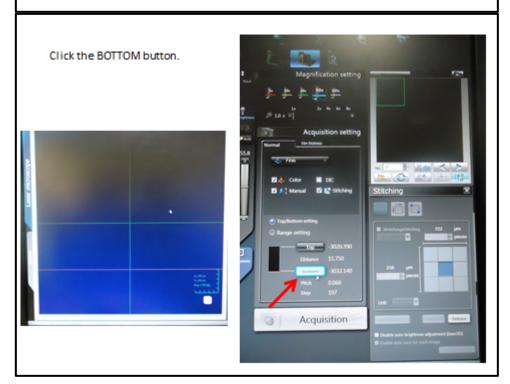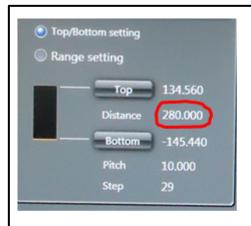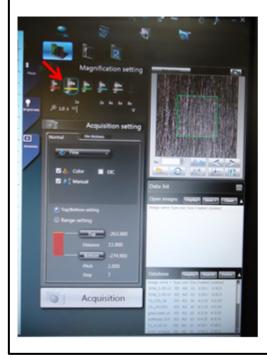
Make sure the microscope does not crash into the surface when moving to a larger magnification. The difference between the TOP and BOTTOM is the distance. Make sure the distance is not greater than the standoff (WD) of a particular lens.
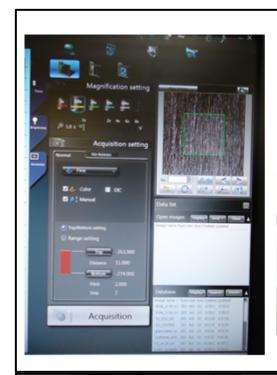
Lens	Magnification	FOV(µm)	WD(mm)	Numerical Aperature
5x	108x-864x	2560-320	20.00mm	0.15
10x	216x-1728x	1280-160	11.00mm	0.3
20x	432x-3456x	640-80	1.0mm	0.6
50x	1080x-8640x	256-32	0.35mm	0.95
100x	2160x-17280x	128-16	0.35mm	0.95
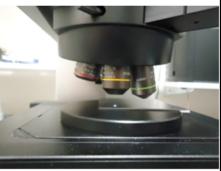
Lets move up to the 10X.
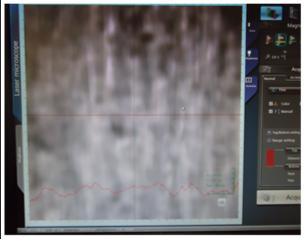
Click the 10X to change to the next magnification.
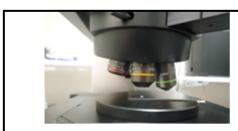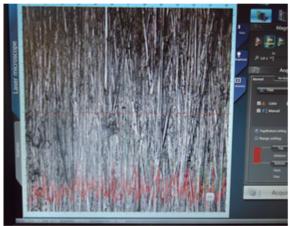
The image is blurry. You need to scroll with the mouse until the image is in focus.

Click the mouse to scroll and focus the image.
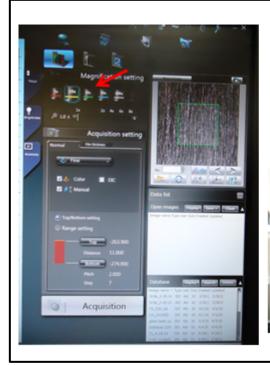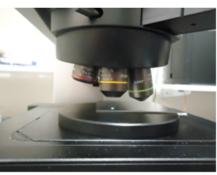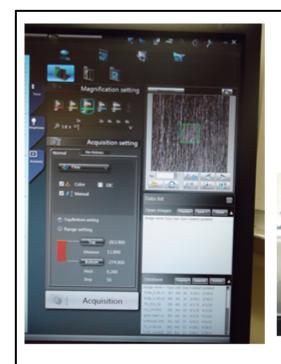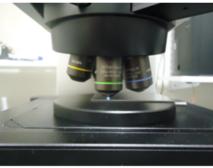
Now the image is in focus and we can move up to the 20X magnification.
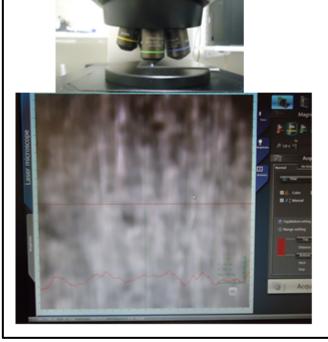
Click the 20X to move to the next magnification.
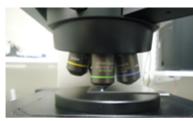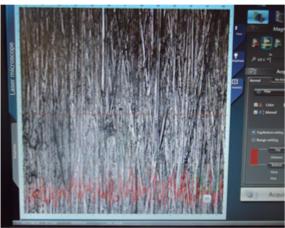
The image is blurry. You need to scroll with the mouse until the image is in focus.
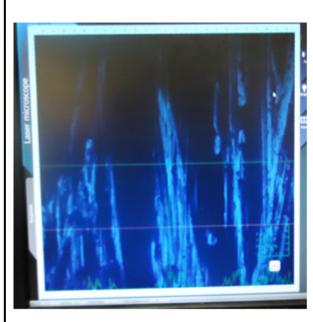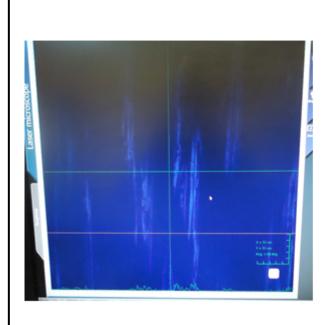
Click the mouse to scroll and focus the image.
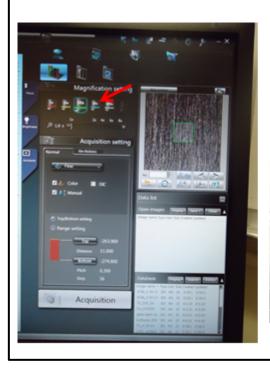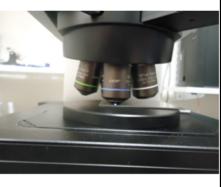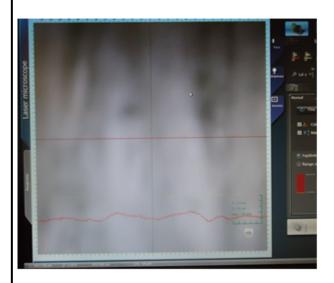
Now the image is in focus and we can move up to the 50X magnification.

Click the 50X to move to the next magnification.
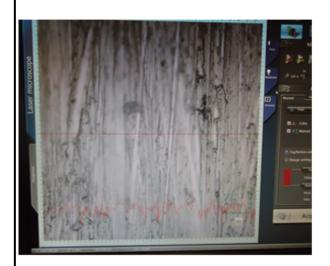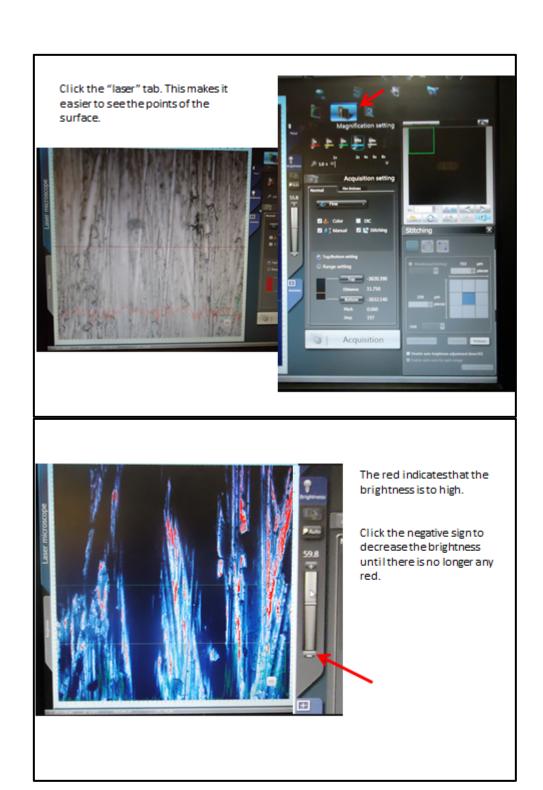
The image is blurry. You need to scroll with the mouse until the image is in focus.

Click the mouse to scroll and focus the image.

Now the image is in focus.

Click the "laser" tab. This makes it easier to see the points of the surface.

The red indicates that the brightness is to high.

Click the negative sign to decrease the brightness until there is no longer any red.

Now we need to define the highest (TOP) and lowest point (BOTTOM) of the measurement by scrolling up (for TOP) and down (for Bottom).

Lets start with the top.
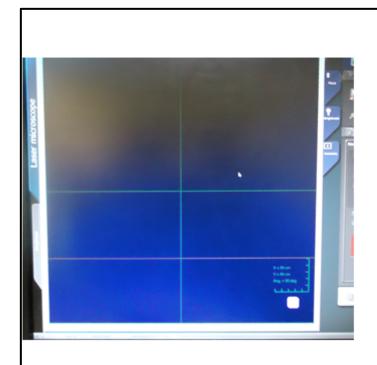
Click the mouse to scroll up until the screen is completely blue.

Now we can define the "TOP."

Click the "TOP" button to define the highest point of the measurement.

To define the BOTTOM, click the mouse to scroll down until the screen is completely blue again.

Now we are at the bottom.

Click the BOTTOM button.

Click "Acquisition" to start measuring the surface.

Measuring surface...

Here is the surface measurement.
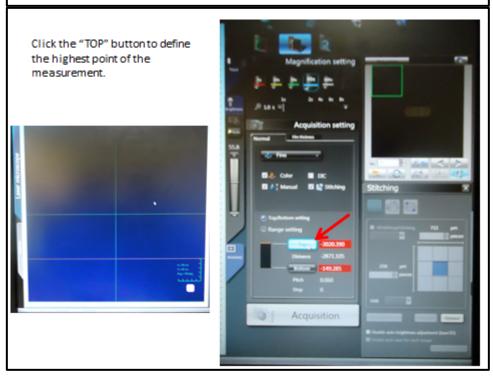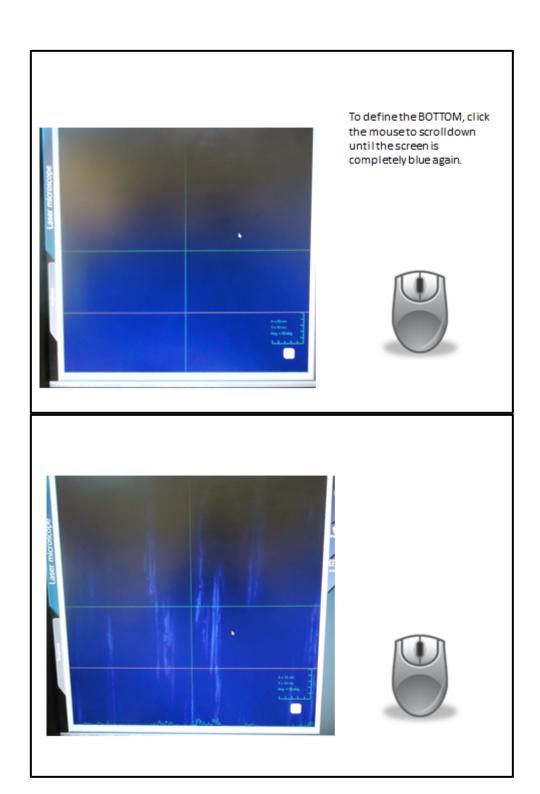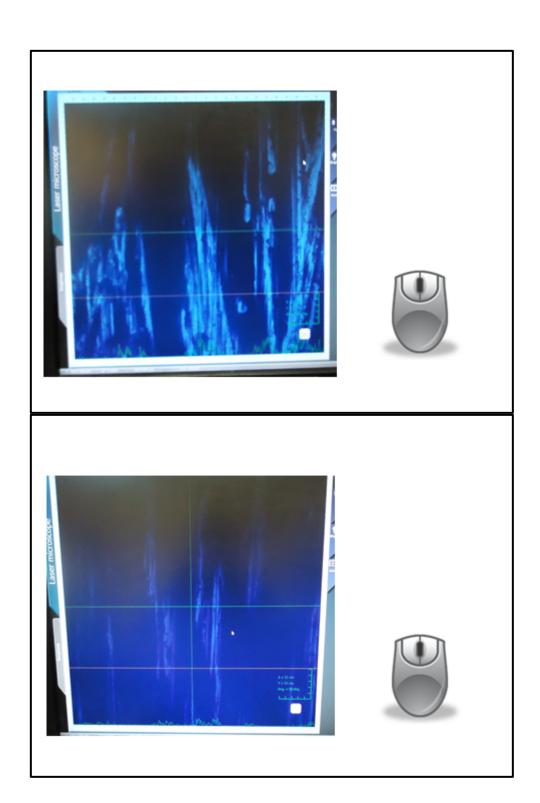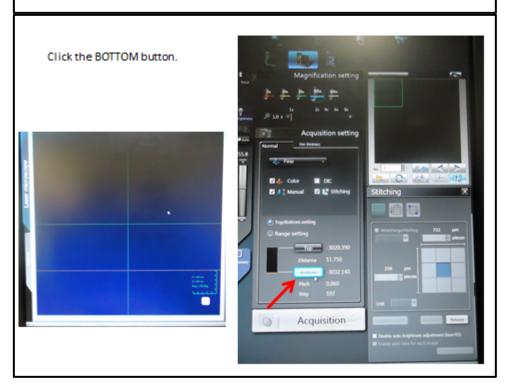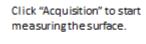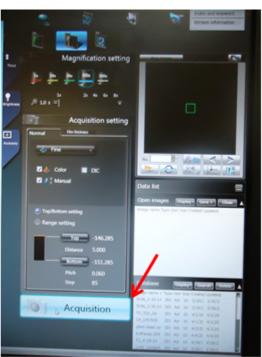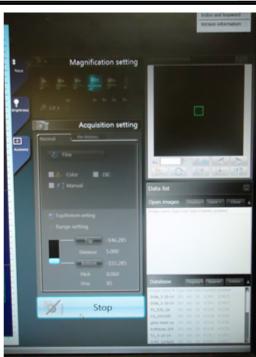
Below is a 3d image of the surface.

7.4 Appendix D: Measurements Taken with Olympus LEXT OLS4000
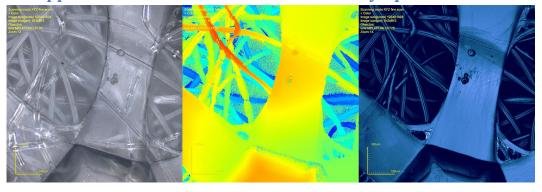
Figure 12 Band-Aid - Padding
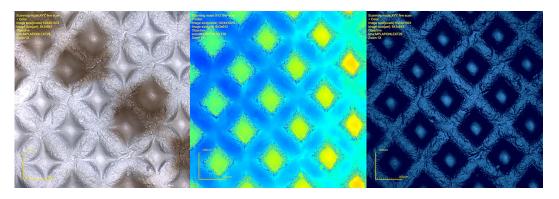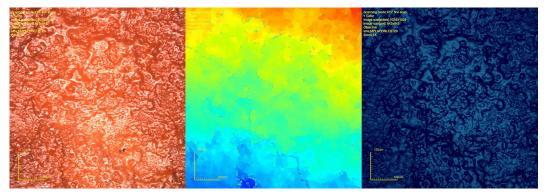

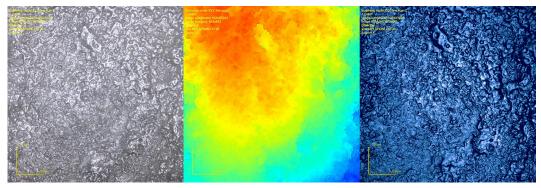**Figure 13 Band-Aid - Top Part**

Figure 14 Candy Corn Orange Part

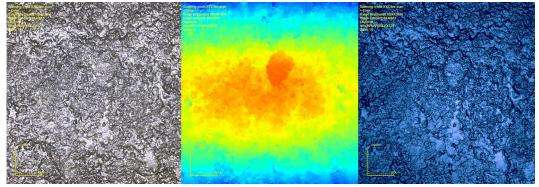**Figure 15 Candy Corn White Part**

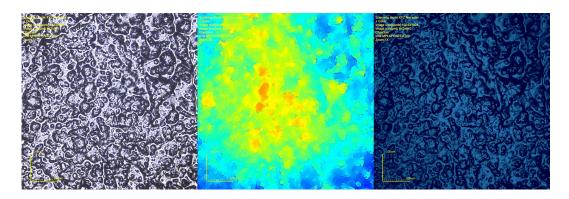**Figure 16 Candy Corn Yellow Part**
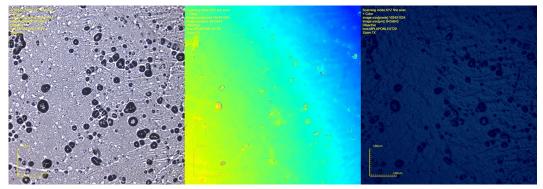

Figure 17 Dot (candy) - Green

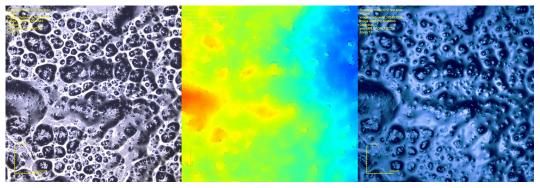**Figure 18 Dot (candy) - Orange**

Figure 19 Dot (candy) - Pink
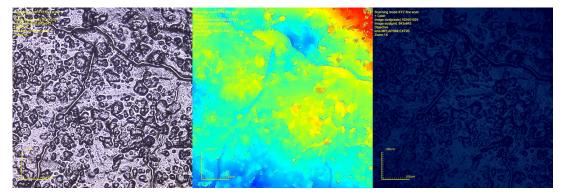
Figure 20 Dot (candy) - Red
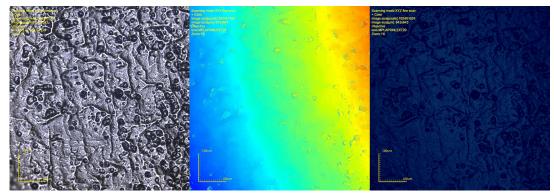
Figure 21 Dot (candy) - Yellow
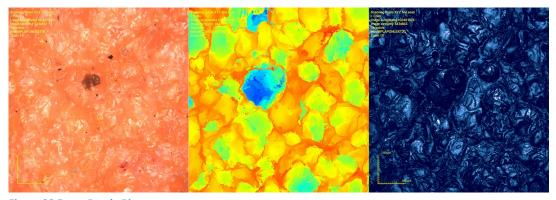
Figure 22 Foam Puzzle Piece
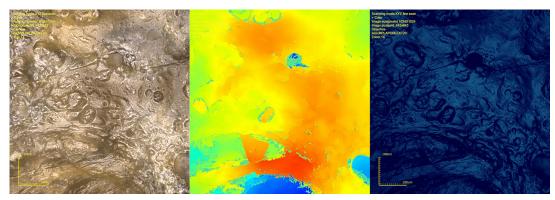
Figure 23 Fortune Cookie
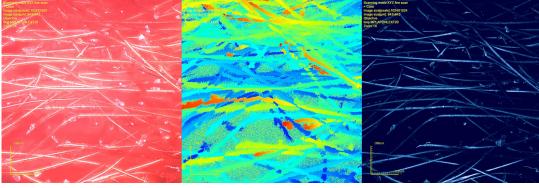
Figure 24 French fry Key Chain
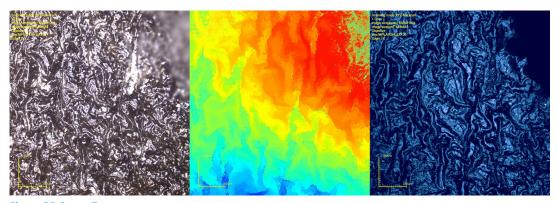
Figure 25 Green Tea
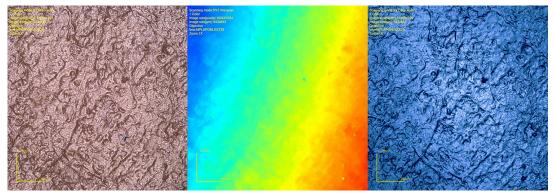
Figure 26 Hershey Kiss
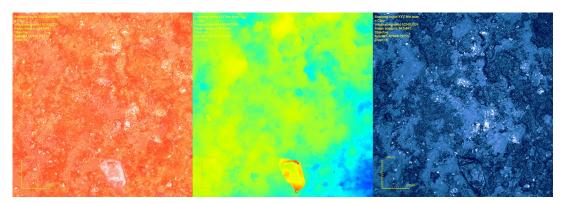
Figure 27 Ibuprofen
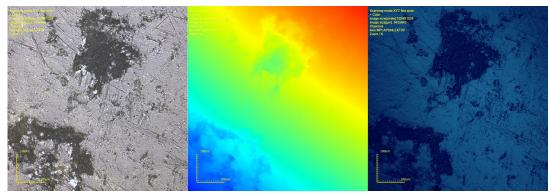
Figure 28 Lemonhead
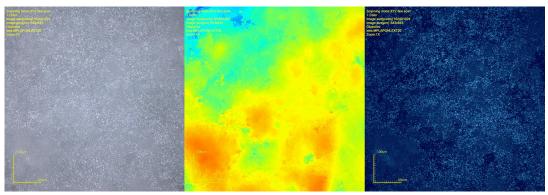
Figure 29 Mentos
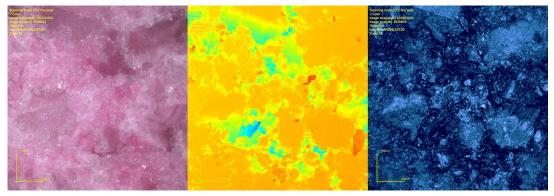
Figure 30 Pez – Cherry
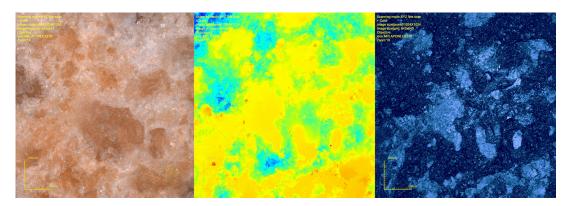
Figure 31 Pez - Orange
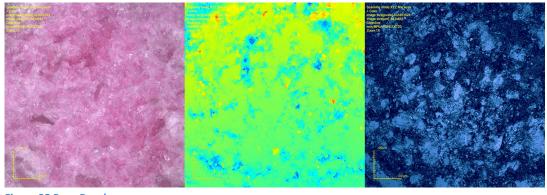
Figure 32 Pez - Raspberry
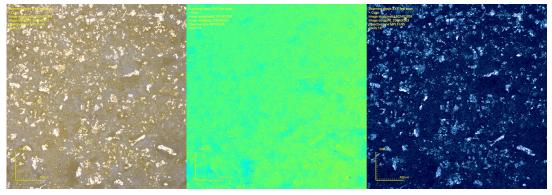
Figure 33 Pez - Yellow
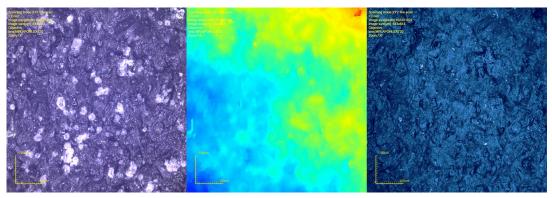
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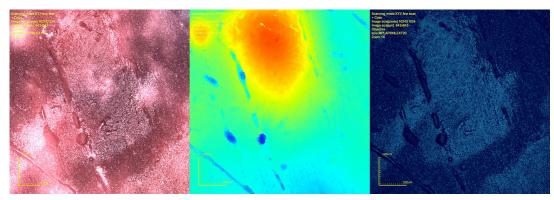
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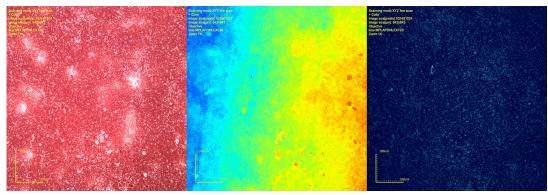
Figure 36 Redbird Peppermint Red Part
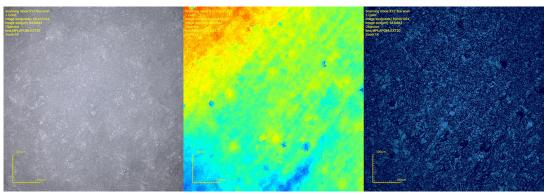
Figure 37 Redbird Peppermint White Part
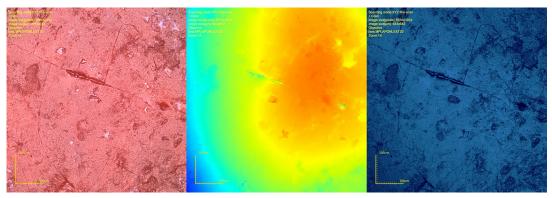
Figure 38 Skittle - Red
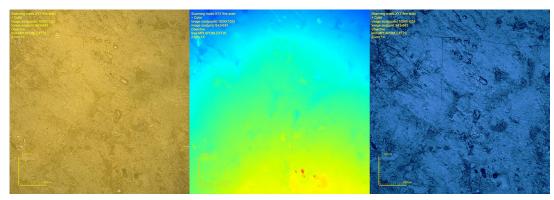
Figure 39 Skittle - Yellow
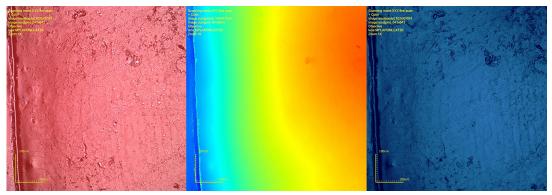
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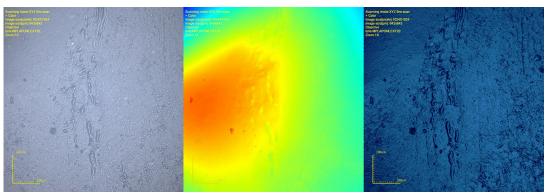
Figure 41 Starlight Mint White Part

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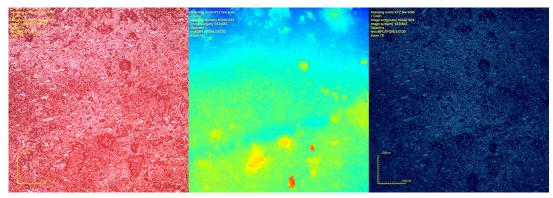
Figure 42 Sweet Stripes Red Part
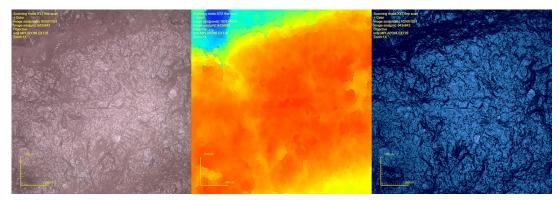
Figure 433 Trident Layers Gum
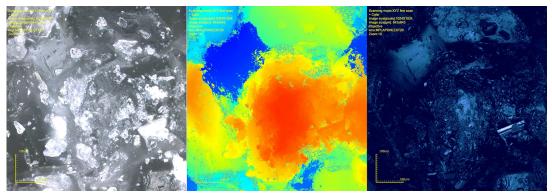
Figure 44 Trolls Sour Crawler
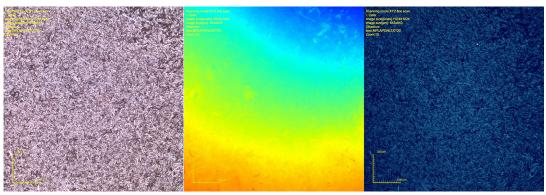
Figure 45 York Chocolate

7. 5 Appendix E: Robert L. Russell's "The Top Ten Points for Designing Engaging Exhibits"

1. Provide advance organizers
   a. <u>Exhibit titles should convey essence of exhibit</u>- Each exhibit titles does this effectively.
   b. <u>Big ideas help visitors organize exhibit experiences</u>- The virtual microscope tutorial may be very specific and not considered broad enough for a visitor with little experience. We do believe that the ricebox, art gallery, and cabinets are big enough ideas for inexperienced visitors to feel confident with.
   c. <u>Provide visitors with obvious starting points</u>-we should make sure that the surface metrology exhibit as a whole has an intro exhibit that explains surface metrology in general and briefly introduces what all the sub exhibits should be conveying. As far as specific exhibits this is our assessment:
      i. Virtual Microscope Tutorial- There is a clear starting point when the visitor walks up to the computer screen or tablet. The first title has a good introduction.
      ii. Augmented Reality Ricebox- The sandbox by itself is not enough. Visitors may not intuitively know that they can move the sand without direction. In addition there should be some explanation near the ricebox of its correlation to surface metrology otherwise playing with the ricebox does not withstand its learning purposes.
      iii. Surface Art Gallery- This exhibit does not have a "starting point," and is less demanding in terms of visitor participation.
   iv. 3D Surface Cabinets- The "starting point" of this exhibit is looking and touching the 3D printed surface of the cabinet door. However, it may need to be specified that this exhibit can be touched and also requires interaction by opening the cabinet.
   d. <u>Theme exhibits for greater visitor involvement</u>- The surface metrology exhibit is divided into four sub-exhibits, each with its own theme.
2. Design accessible, attractive, inviting, involving environments
   a. <u>Inviting and attractive exhibit design</u>- cannot be determined at this point
   b. <u>Provide comfortable, safe, and secure exhibit environments</u>- all exhibits
   c. <u>Design for non-intimidating environments and non</u>-distracting environments-sandbox may be the only intimidating exhibit since visitors are not use to being able to actually touch exhibits. Also it may be distracting since the purpose of the exhibit is to learn surface metrology concepts, however this exhibit has a tendency to be used as a toy
   d. <u>Design physically and intellectually accessible activities and content</u>-cannot be determined at this point
   e. <u>Design for some immersive exhibit experience</u>- The 3D surface cabinets may not be considered immersive
3. Design accessible and easy-to-use exhibits

    a. <u>Use good mapping (easy to see what to do, the relation between actions and results, controls and effects)</u>
        i. Virtual microscope tutorial-good mapping
        ii. Sandbox-we need to make sure we make clear what to do
        iii. Gallery-requires minimal mapping
        iv. Cabinets-we need to make clear that touching and opening cabinets is art of the exhibit and is allowed
    b. <u>Use appropriate technology, media</u>- virtual microscope tutorial and sandbox make use of various technologies conducive for interactive learning
    c. <u>Design to provide visitors with a sense of direct engagement</u>-all exhibits provide this
    d. <u>Design for visibility (can look at exhibit and easily see alternatives to action)</u>-N/A
    e. <u>Design for simplicity</u>-virtual microscope and sandbox can be simple if visitors are given proper instruction
    f. <u>Design so that visitors can use information available in the world (low-reliance on remote instructions to operate exhibit)</u>- the ricebox exhibit may have remote instructions and be not as intuitive based on everyday knowledge
    g. <u>Design for error (so visitors find it easy to get started again)</u>- it is difficult to error in these exhibits
    h. <u>Standardize exhibit graphics and interfaces so visitors can generalize some functional knowledge (e.g. where to find directions on how to use exhibits) from one exhibit to the next.)</u>- The art gallery has no or little interface as far as required direction, however our interfaces for the ricebox, virtual microscope tutorial, and cabinets are very different. For each we could make sure that the directions are always in front of the entrance of the exhibit.

4. Present real objects/phenomenon
    a. <u>Present genuine, real objects and phenomenon</u>- each exhibit does this well
    b. <u>Design emotionally and intellectually involving experiences</u>- the art gallery will be better for both; the ricebox and tutorial will be intellectually involving; the cabinets may not be as intellectually involving since it is very simple, however as mentioned in…cabinets of curiosities cater to visitors enjoyment of discovery
    c. <u>Design for the "Wow" factor</u>-Only sandbox provides "Wow" factor

5. Meet visitor expectations
    a. <u>Design so visitors can have some fun</u>- interactive exhibits, especially sandbox provide visitors with fun
    b. <u>Design to meet the expectations visitors have for educational experience</u>- to be determined
    c. <u>Design to encourage social interaction</u>- "Public art exhibitions are seen to encourage family and social interaction (Johanson and Glow 2012)."
    d. <u>Design to engage all the senses</u>- sight, touch, auditory; does not engage taste and smell
    e. <u>Design to pique curiosity, surprise and intrigue</u>- to be determined
    f. <u>Design to instill a sense of confidence</u>- to be determined

6. Provide entry points to meet individual visitors' needs

a. <u>Design to meet the needs of high-priority target audiences-</u> our target audience is WPI students who have minimal exposure to surface metrology. Their needs are more information on the topic and how it applies to their major or interests.

b. <u>Do front-end evaluation to identify target audience knowledge, interests, and reactions to proposed exhibit elements-</u> we have not yet competed this part; however the way in which we would go about is to send out a survey to all WPI students and/or have students complete a survey in person before entering the exhibit.

c. <u>Use mixed-media to meet interest and needs of visitors of different ages, interests, and cultural backgrounds-</u> each exhibit has a different interface and meets variety by using different technologies. The surface art gallery for example engages visitors with interests in art.

d. <u>Provide appropriate tools to allow visitors to use exhibits effectively-</u> the virtual tutorial is the only exhibit with proper instruction at the moment. Galley does not need instruction.

e. <u>Posing a question (or causing visitors to pose their own questions) provides the prime motivation for visitors to get started and continue along the inquiry path.</u>-The main question the exhibit in general poses is *How can surface metrology be applied to your life* or *How would you use surface metrology* or *What surfaces would you like to study*

7. Offer visitors choices, control, feedback, and success

a. <u>Provide built-in goals, natural goals inherent in the experience</u>-the microscope tutorial teaches visitors about the microscope by accomplishing small goals by following the step-by-step process in the tutorial. The 3D surface cabinets provide a goal of finding out more information about the surface of the cabinet by looking inside the cabinet for more information.

b. <u>Provide open-ended (not too open-ended) options-</u> all of the exhibits are varied in levels of interactivity. Each exhibit is interacted with in a different with only the gallery being the only exhibit that the visitors cannot physically interact with.

c. <u>Make available multiple inquiry paths with clear procedures-</u> the microscope tutorial provides a clear set of procedures to precede through the tutorial. The 3D Surface Cabinets are straight-forward in design so that people know how the cabinets work without detailed instructions. The ricebox may need explanation on its function and how to interact with it but it would still be easy for the visitors to understand.

d. <u>Layer experiences and labels-</u> each exhibit would have its own set of instructions nearby and the necessary labels needed for explanation.

e. <u>Offer sequences of actions at increasing levels of complexity-</u> each exhibit has different levels of complexity. The Surface Art Gallery is the simplest for it is just a gallery that does not require physical interaction. The Virtual Microscope Tutorial is simple and has step-by-step instructions but requires physical interaction. The 3D Surface Cabinets also require the visitors to interact with the exhibit to find out answers but the mechanisms of the cabinets are straight-forward and easy to understand. The Augmented Reality Ricebox is the most complex since there is more need to provide more explanations and instruction.

f. Continual challenge and feedback- the exhibits have different levels of difficulty but not all of them provide much feedback. The exhibit that provides the most feedback is the Virtual Microscope Tutorial since it is a step-by-step tutorial for the visitors. The other exhibits such as the gallery, cabinets, and ricebox may need a tour guide to provide feedback since the exhibits themselves provide little.

g. Opportunities to manipulate variables with clearly observable results- The Augmented Reality Ricebox provides visitors the opportunity to see and learn about topographical changes by manipulating the surface of the sand and seeing the topographical changes on the monitor.

h. Visible exhibit components- All of the exhibits would be brightly colored or large so they would all be visible.

i. Provide "natural" indications of success (a result, such as a building standing up, a chemical reaction). – The Virtual Microscope Tutorial is the only exhibit that has the most visible goal to achieve by having the visitors successfully finish the tutorial. The 3D Print Surface Cabinets provide the success of finding more information about the surface. The gallery and the ricebox do not have a clear goal for the visitors to achieve since both of them are open-ended.

8. Support direct experiences with labels, staff explainers, and opportunities for cooperative engagement

a. Provide labels/staff explainers directly supporting exhibit experiences that: Identify what's there, Point out things to notice, Provide instructions, Suggest things to do, Raise questions, Answer questions, Connect to other experiences, Place in context.- labels will be placed around or in the exhibits providing explanation and instructions to the visitors.

b. Encourage cooperative engagement by: Providing collaborative activities for parent/child, peers, and family groups, Suggesting opportunities for conversation, Physically designing exhibits for multiple participants.- the ricebox exhibit would be an ideal place for social interaction since the ricebox would be large enough for several people to interact with at once. The 3D Print Surface cabinets could also be interacted with multiple people at once.

c. Provide related educational programming (films, demos, etc. are a part of many museum experiences), such as Demonstrations, Discovery carts, Facilitated activities, experiments in exhibit, Take home materials- plan to include pamphlets to be given out, and videos to be displayed on monitors. The ricebox exhibit allows visitors to experiment with the ricebox and see how they are affecting the topographical measurement of the surface.

9. Provide support for follow-up educational experiences

a. Provide related books in resource area, gift shop, libraries- not included

b. Provide Web page resources.-planned to be included

c. Provide follow-up classes, field trips, outreach-direct to surface metrology lab for further information and learning

d. Provide leads to other community resources- not included
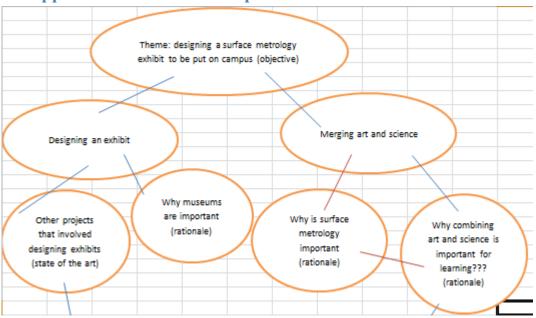
e. Point out opportunities to work on related projects in museum.-surface metrology lab

10. Evaluate

   a. Front-end evaluation can help provide starting points for exhibit design by identifying visitor knowledge, interests, and preferences.-planned to be included

   b. Formative evaluation can improve the quality of exhibits by identifying mechanical and conceptual elements that need revision.- not included

   c. Summative evaluation can help assess the overall effectiveness and outcomes of the exhibit experience.- post- visit evaluation in Appendix F (Russell 2000)
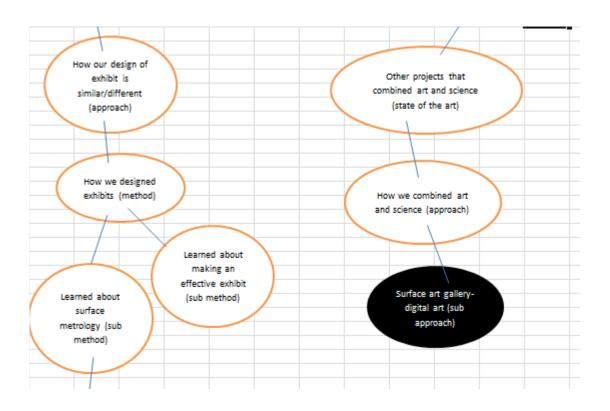
7.6 Appendix F: Post visit evaluation
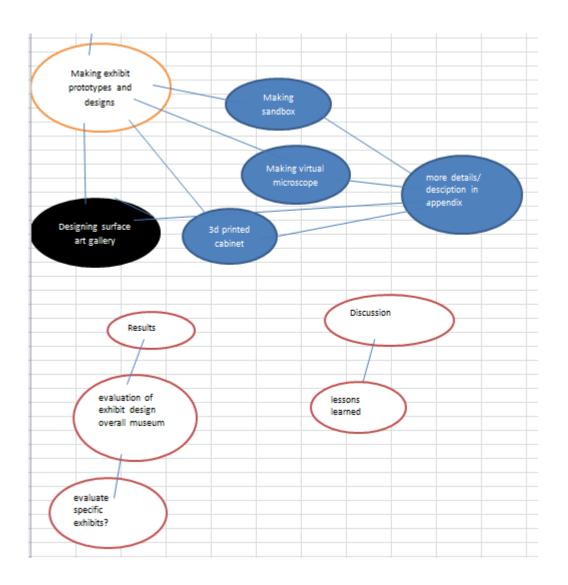
The following is a form visitors will be asked to fill out after their visit in order to evaluate the quality of the museum exhibits.

1. What stood out the most to you during your visit?
2. What do you think was the most important thing to take away from the Surface Measurement Art Gallery?
3. What do you think was the most important thing to take away from the Augmented Reality Ricebox?
4. What do you think was the most important thing to take away from the 3D printed Surface Cabinets?
5. What do you think was the most important thing to take away from the Virtual Microscope Tutorial?
6. Did the museum pique your interest in surface metrology?
7. Did you feel engaged in each exhibit?
8. On a scale of 1(least) to 10 (most) did you feel the exhibits provided educational value?
9. On a scale of 1 (least) to 10 (most) how much fun did you have during your visit?

7.7 Appendix G: Theme Decomposition

Theme: designing a surface metrology exhibit to be put on campus (objective)

Designing an exhibit

Merging art and science

Other projects that involved designing exhibits (state of the art)

Why museums are important (rationale)

Why is surface metrology important (rationale)

Why combining art and science is important for learning??? (rationale)

How our design of exhibit is similar/different (approach)

Other projects that combined art and science (state of the art)

How we designed exhibits (method)

How we combined art and science (approach)

Learned about making an effective exhibit (sub method)

Learned about surface metrology (sub method)

Surface art gallery- digital art (sub approach)

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