WORCESTER POLYTECHNIC INSTITUTE

MARS SETTLEMENT & FABRICATION EXHIBIT DESIGN PROJECT

IQP FINAL REPORT

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4/30/2012

The Mars Exhibit Design project details the necessity of expanding the reach of STEM curriculum to junior high school students for the safety of the future of scientific and technological advancement. The project explores how museum exhibits can be utilized as highly effective teaching devices and presents an exhibit design centered on polymer science, 3D fabrication, and how it relates to the settlement of Mars.

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II. Introduction

Among humanity's most important responsibilities is that of inspiring the present and future generations with a hopeful future, inspiring them to use technology wisely, to expand beyond the limited resources and size of Earth, and to respect the Earth's environment. Toward these ends, our team worked with The Mars Foundation to design a museum exhibit focused on the exploration, settlement, and development of Mars. This exhibit teaches science and engineering concepts ranging from polymer science to 3D fabrication to the considerations of extraterrestrial travel and settlement. The exhibit is designed to appeal to and best-engage with junior high school students because the sponsor and our team established that this age range is the most important in the near future of our technological advancement. It raises awareness of that it is practical to extend life beyond the Earth, within our lifetimes. Everywhere else beyond the Earth is currently a harsh and inhospitable environment. It is possible, but not easy, to establish life on Mars and elsewhere. This will raise the public's consciousness that the Earth is a wonderful environment which we should cherish and protect, even as we move beyond it.

Accordingly, our work has been to develop a tool to inspire and interest the next generation of scientists and engineers. The medium we chose for this tool is a museum exhibit designed to appeal to and best-engage with junior high school students. The choice of this age range was because the sponsor and our team established that this group is the most important in the near future of our technological advancement. The exhibit teaches science and engineering concepts ranging from polymer science to 3D fabrication to the considerations of extraterrestrial travel and settlement. While these concepts cover a wide range, they are interconnected and all tie back to the overall theme that we are not bounded by the gravity of earth, and that if enough motivated people are involved in technological fields working towards a goal, it can be made a reality.

We provided our sponsor with an exhibit design portfolio for use with professional exhibit design companies, website content on their homepage and blog for public visibility, and a proposal to give to sponsors to gain their interest and support in the construction and implementation of this exhibit. Our IQP's work provides the Mars Foundation with an exhibit capable of capturing the inquiring minds of children and inspiring them to further investigate science, technology, math, and engineering disciplines. This exhibit will inspire future minds to turn current theory into practice.

1. Background

1.1 Teaching Through Exhibits

Before creating this exhibit, it is necessary to understand how to interact and establish a connection with our selected audience. We must be familiar in what factors to consider when making an interactive exhibit. To connect with our audience and make an effective presentation to them, we need to understand what the visitors in our audience want, expect, and respond to when they visit an exhibit. We will collect this information through research on and excursions to related exhibits. From this information we will analyze how they attract visitors and impact their audience. Another major goal of our project will be to establish outreach between the exhibit and schools and educators.

1.2 Types of Exhibits

The purpose of an exhibit is to educate the visitor based on the topic the exhibit is showing. There are two types of exhibits: information-based and experience-based. Information-based exhibits use a variety of displays, informational text and videos to inform the visitors. History exhibits use time- lines as well as physical displays, such as artifacts, to provide visitors factual information. Unlike information-based exhibits, experience-based exhibits rely on active involvement, both physical and mental. Physical components in these exhibits can be touched, smelled, felt, heard, or manipulated in some way. They provide some kind of information or invoke feelings that cannot be had by simply viewing an object[1]. The physical experience greatly affects the mental experience. When visitors are engaged with the exhibit, they use their senses to analyze what is in front of them, allowing them to raise questions and continue through the exhibit to answer them. Exhibits focusing on science, art, and animals allow visitors to use their senses to understand and analyze what is in front of them. In this project, our exhibit will be developed to be primarily an interactive experienced-based exhibit.

1.3 Designing Attractive and Engaging Displays

1.3.1 Interaction

Displays of objects are good ways catch the visitor's eye. Large, moving, or rare displays have been proven to produce longer viewing times from visitors than smaller, stationary, and common objects.[2] This phenomenon is a consequence of the fact that people go to museums to observe something they don't normally see or experience in their daily lives. Any good exhibit needs to present something that will wow the audience.[3] For example, the Hope Diamond at the Smithsonian Museum of Natural History attracts many visitors because of its mysterious backstory and beauty. Visitors want to get the most out of the

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[1] Andrew Peakarik and others, Developing Interactive Exhibits at the Smithsonian (Report, Smithsonian Institution, 2002).
[2] Steve Bitgood and Don Patterson, *Principles of Exhibit Design, Visitor Behavior 2, no. 1* (Jacksonville, AL: Psychology Institute, Jacksonville State University, 1987), 4-6.
[3] Ibid

exhibit, and want to use all of their senses to understand what is in front of them, especially if the exhibit at hand is focused on identifying with and reaching out to children. Having objects that one can smell, hear, touch, and see increases the amount of viewing time for visitors. Technology is becoming increasingly popular, especially with the younger generations, and accordingly, museums are providing more exhibits with multimedia interactivity. Touch screens enhanced with audio and video enhance the visitors learning. These technological gateways give exhibits a direct avenue with which to challenge visitors. They help to create exhibits that allow visitors to induce change and observe different results. Throughout our exhibit, there are numerous touch screens that engage visitors with interactive activities. A LCD television facing the visitors is displayed in the fabrication exhibit to mirror what the presenter sees on his monitor.
A balance needs to be struck with the difficulty of the interactive exhibit based on the target audience's abilities; if it is too difficult or too easy, they may become disinterested. However, if the difficulty is appropriate for the audience, the successful completion of the activity provides the audience with a much stronger educational experience and establishes a memory pathway for further investigation and learning.

The exhibit should provide labels and staff members that will enhance the visitors learning. The exhibit-goers will be able to identify what is there, point out things to notice, provide instructions, and suggest what to do, and raise as well as answer questions. A staff member would be included in our exhibit to demonstrate and maintain the printer, and answer any questions visitors might have.

Exhibits also encourage cooperation and stimulate conversations with other visitors to work together to complete an activity. This occurrence, known as triangulation, makes the exhibit more memorable and enjoyable for all who visit and participate. Exhibits that pose a physical and/or mental challenge require teamwork to complete the activity. Peers, families, and even individuals working together find these types of exhibits more fun than exhibits meant for one person, and often take more away from the exhibit. With our exhibit, the activity will promote teamwork to complete the task while visitors have fun learning how 3D printers work.

1.3.2 Visibility

Visibility is essential when designing an exhibit. The more visible the object is, the more attention it receives from visitors. Objects and exhibits on display towards the front are looked at first, and are the first opportunity to grab the visitor’s attention. Visitors like to observe with their hands, especially children. Having visitors come up close to an object creates more viewing time. The position of the object is also an important factor. Objects placed at eye level increases the visitor’s attention span. A study from A. Melton showed that objects placed in upper row positions received more attention that lower ones, but central positions worked the best.[4] Our centerpiece is the 3D printer, and has shown to attract attention with our audience. It has many moving parts, it makes noise, and lights up when turned on. It is a great eye catcher.

[4] Bitgood and Patterson, *Principles of Exhibit Design*

When designing an exhibit for children, color is important. It helps the overall atmosphere and brings personality to the exhibit. Once a topic has been decided, a basic scheme of colors can be chosen. For example, for our exhibit, we chose red and rustic colors as our primary colors to mimic the planet. Once primary colors are selected, it is easy to compliment these with other colors to make text, displays, and pictures stand out. It is also good to keep the design simple. Too many colors, shapes, and photos can confuse them and take away the visitor's experience.[5]

1.4 Establishing a Connection with the Audience

An important thing to keep in mind is that every visitor is different. Therefore, one must consider certain factors to please people of all ages, gender, status, and ethnicities. Since a museum is open to visitors for all age groups, it is important to design exhibits to accommodate them. Children view, act, and think differently than adults do. Therefore, when focusing on an audience with both children and adults, make sure to include material both age groups can understand. Provide media that appeases both the older and younger audiences.

An interactive exhibit is ideal for younger audiences, which is what our exhibit will focus on. According to Crowley and Callanan, interactive components within the exhibit increase the potential learning experiences for children.[6] That is, children are able to learn more from interactive components in the exhibit than from static components. Most children learn through interactive learning, which is especially encouraged in school curriculums. Exhibits use the same interactive learning in schools through attractive displays, sensory items, and many other factors.

In our attempt to connect with our audience, we have many interactive components within our exhibit to engage our audience. The students will not be able to touch the 3D printer, but the printer itself is moving. Children focus their attention more on objects that move than stationary ones, as stated in the previous section. Our activities for the students are hands-on and secretly serve as a mental puzzle to challenge them using what they have just learned to complete the activity.

1.5 Building to Last

All materials within an exhibit must be durable, washable, and safe for children. Children like to touch everything. To avoid spreading germs, the exhibit must be kept clean so other children can use it. When designing, make sure that standard cleaning products are safe on the materials used in the exhibit. A lawsuit could result if someone's child got hurt or ill from the exhibit. So it is also good to keep in mind materials that are safe for

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[5] Kevin Crowley, Takeshi Okada, and Christian D. Schunn, *Designing for Science*, (Mahwah, NJ: Lawrence Erlbaum Associates, Inc., 2001), 39

[6] Catharine Fishel, *Designing for Children*, (Gloucester, MA: Rockport Publishers, 2001), 105.

children. Surfaces of materials should be smooth and edges should be rounded. Transparent plastics are great keeping fluids and small objects in as well as protecting screens and displays not meant for touching. It is important to think of materials that will not only be safe to touch, but also strong. Objects that are handled by many visitors must be durable so they do not break easily. Plexiglas and other strong plastics are used mostly in exhibits geared toward children. Objects that are fastened together must be tightly screwed or glued. For our exhibit design, we intended to make the exhibit sturdy and childproof. Strong plastic is used for panels on display. Touch screens are reinforced with a touch sensitive material that is protects the glass screen. Items in the fabrication exhibit are made out of ABS plastic, the same kind of plastic used in Legos.

1.6 Current Mars Exhibits

For creating an exhibit on the future colonization of Mars, it is a good idea to look at existing exhibits that are showcased in the world. The most recent and closely related exhibit today is the Facing Mars exhibit.

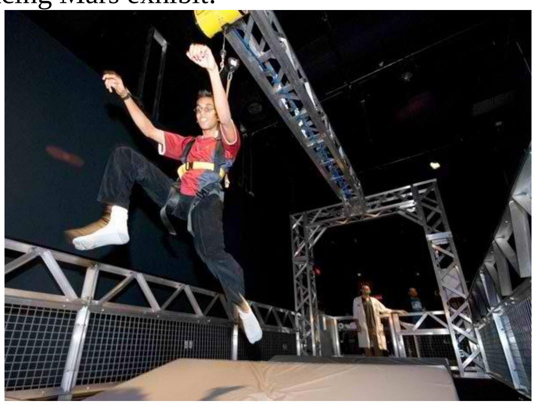

Figure 1.6-1:"MarsWalk" exhibit simulates what walking on Mars feels like.

Designed by the Ontario Science Center, this interactive exhibit was created to educate people about the physical, psychological, and scientific obstacles in traveling and settling Mars[7]. It displays 28 exhibits, covering all topics from Walking on Mars to Mars Flyover. Before visitors enter, there is a proposed question: Which planet would you rather live on? Visitors walk through either the Mars or Earth gate. Then, they come across a screen displaying terrain that could either be from these two planets, and it is up to the visitors to guess which one. Within the exhibit, facts about Mars are along the wall to give background information about the planet. This gives visitors who are not familiar about Mars a small education. Exhibits focus mostly on the effects of microgravity on the human body, transportation to and from Mars, and exploration of Mars's terrain. Each one of the exhibits provides hands-on participation, whether it is pressing buttons to change variables or physically moving throughout the exhibit. Exhibits such as the Spinning Chair test your endurance and knowledge after being spun in a chair for 30 seconds. As for informational-based exhibits, there are TV screens that have scientists

[7] "Facing Mars, "Ontario Science Centre, Accessed November 17, 2011, http://www.ontariosciencecentre.ca/facingmars/

answer the most common disputed questions about Mars exploration. When the visitor leaves the exhibit room, after learning about Mars, he or she is then posed with the same question in the beginning: “Which planet would you rather live on?” They then exit through the corresponding gate. The goals and topics of the "Facing Mars" exhibit are similar to ours, although ours goes beyond the exploration to settlement of Mars. If we can establish connections with the people and foundations behind the exhibit, we may have an opportunity to tap a vital resource for design, support, advertising, or even funding.

1.7 Inquiry Based Learning for Middle School Students

One of the many benefits of teaching children science is that it is one of the more engaging topics for students to learn. If a student finds one topic droll or uninteresting, chances are that there is at least one topic in science that will capture their attention. Not only that, but there are many different styles of teaching that teachers can utilize, no class will be alike. One of these models that teachers can use is called Inquiry-Based Learning, which emphasizes the usage of interactive experiments, and critical thinking skills in order to teach students about a certain subject. Inquiry-Based learning is one of the most powerful teaching methods if executed correctly.

The main intent of inquiry based learning is to get children involved with their learning. Instead of the traditional “Monkey-see, Monkey-do” model, the teacher takes a more passive role in teaching. Students are presented a problem and are given all of the needed tools to solve it. They are then left to their own devices in project teams, and must work together in order to come up with a solution to the problem. The teacher remains present, able to nudge students into the right direction should they veer off the path, but never actually giving students the answers. This forces students to think critically and solve problems in interesting ways.

There are many different explanations as to why this method of teaching works. First of which, according to the Department of Educational Psychology at Rutgers University, in order to efficiently learn, students must construct their own knowledge and build upon it.[8] Because they are left to their own devices, students must actually think and then do, helping to concrete that knowledge in their head for use sometime later. That is, not to say that they are completely on their own. The fact that the teacher is always there, ready to help out should they get lost or stuck, will make it so that the seemingly herculean task is surmountable by the student.

Another benefit of this style of learning is that because the students are actively involved in their learning, they will tend to pay much more attention. Students like to be active. Especially around the Middle School age, students are less likely to have their minds wander when they are directly involved with their own learning. Students also will be

[8] Hmelo-Silver, Duncan, Chinn, *Scaffolding and Achievement in Problem-Based and Inquiry Learning: A Response to Kirschner, Sweller, and Clark(2006),* Educational Psychologist Lawrence Erbaum Associates, Inc. 2007

learning important life skills, such as critical thinking and decision making, knowledge that will be much more useful in the real world than simple facts that are to be regurgitated back to the teacher for a grade.

Though there are many different benefits to inquiry based learning, it's not to be all, end all solution for teaching children. For instance, there is the issue of how students learn differently than each other. For some students, Inquiry based learning will be a welcomed challenge, allowing them to fully unleash their potential. For others, however, it may prove to be overly cumbersome and hindering for their progress. Because a lot of the education style is based heavily on building up skills, if the student were to miss this critical foundation, it would simply set them up to fail. This line of thinking is actually false, as there are many different levels of inquiry based learning. According to Heather Banchi and Randy Bell, "It is only appropriate to have students conducting open inquiries when they have demonstrated that they can successfully design and carry out investigations when provided with the question."[9] The only time a teacher will have an entirely hands off approach to inquiry based learning, is when they know with absolute certainty that their students would be able to handle such a rigorous exercise.

Criticisms on Inquiry-Based Learning style of teaching is that implementations concern themselves less with the actual teaching model, but with the way the research on the subject is handled. According to Kirschner, Sweller and Clark, "In so far as there is any evidence from controlled studies, it almost uniformly supports direct, strong instructional guidance rather constructivist-based minimal guidance during the instruction of novice to intermediate learners."[10] The research is largely done in very controlled environments, they say, and arguments to the contrary should be considered null.

One of the biggest issues with the teaching style is that it's not readily applicable to different subjects. It may work for the sciences, but the practice doesn't lend well to subjects that are more based upon fact recollection, such as in History. Inquiry based learning is based upon the fact that students are effectively teaching themselves. The main focus on science, as it is constantly changing especially in our world today, is that we need to be able to think critically for ourselves, and be able to find the answers. With history based classes, especially at the middle school level, classes are more based on fact recollection, such as dates and names. With science, and especially engineering, a lot of classes are much more hands on, actually enabling students to work with their hands and create something by themselves.

Compared to other methods, such as simple lecture or reading, inquiry based learning is one of the most powerful tools in teaching children science. For starters, from the get-go, the students are involved. They are taking direct control of their learning and can learn at

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[9] Bell Banchi, "The Many Levels of Inquiry," *National Science Teachers Association,* (2008)

[10] Kirschner, Sweller, Clark, "Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivists, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching," *Educational Psychologist*, Lawrence Erbaum Associates, Inc. (2006)

their own pace, with gentle nudging from the teacher. The amount of involvement that teachers have in students' learning is also variable, allowing the teacher to get involved more with a class that's struggling or less with one that has more advanced students. Finally, it gets the students involved, ensuring that their attention is focused on the project on hand, as well at their own learning, one of the many concerns of a teacher trying to teach any kind of subject.

1.8 The Massachusetts State Department of Education STEM Curriculum

The State of Massachusetts has a rather robust curriculum for Science and Technology, covering a great deal of topics throughout a student's career in the school system. Each student is required to take science classes throughout their time in the school system every single year, with topics largely being static from grades k through 5, and allowing student elected topics from 6th grade and onwards. Topics range from various fields in order to give students a good foundation for when they eventually move onto high school, where they ultimately branch out and begin to focus on topics that interest them more.

The Massachusetts Department of education holds science education in very high regard. According to the 2006 curriculum framework, "The purpose of science and technology/engineering education in Massachusetts is to enable students to draw on these skills and habits, as well as on their subject matter knowledge, in order to participate productively in the intellectual and civic life of American society and to provide the foundation for their further education in these areas if they seek it."[11] As such, science education is generally taken very serious in Massachusetts, and the guidelines are very clear in what students will be focusing on learning as they progress through their school career.

Included within the education guideline document is a smattering of different kinds of curriculum activities that would be done in the classroom, giving use a glimpse as to how most classes would be run. Page 38 of the document shows an example of inquiry based teaching in a high school setting. A teacher begins the lesson by discussing the current topic of focus with students, asking for their baseline knowledge of how rivers affect geologic materials. The lesson plan then turns into an interactive portion, where students are brought to the Merrimack River to observe where erosion takes place, and how fast the water was going, in order to reinforce the lesson plan. We can lift from these ideas and bring students a lesson that is just as interactive, especially considering the fact that we have a 3D printer, something tangible that they can interact with.

From the 2nd grade and onwards, students are taught about the Earth's role in the solar system, briefly touching upon the other planets as a contrast to Earth. Students are given small factoids about the other planets, but the focus remains consistently on Earth, as it is something they can actually see and can relate to. This remains the main focus of science education until the student reaches high school, where most, if not all forms of education

[11] Dr. David P. Driscoll, "Massachusetts Science and Technology/Engineering Curriculum Framework," (Report, Massachusetts Department of Education, 2006)

about the solar system stops. This gap allows us a bit of breathing room when planning the exhibit and school presentations, as we can safely assume that students are aware of basic facts about Mars, but haven't gone too in depth about the planet.

Education is not limited to facts, however, which is something to be applauded. Much of the curriculum also seeks to reinforce topics used in the study of science, such as critical thinking and planning skills, which will ultimately help the student to become well rounded. This proves as a boon for our target age range, as during that time, students are being taught how science is constantly evolving, and the way we think about things and solve problems changes as new technology is developed. This works well for our project, as we are trying to push how the advent of the 3D printer and its eventual proliferation as a tool, will eventually lead us to Mars. We also can provide various activities when presenting to a classroom that involve critical thinking skills and new technology.

1.9 3D Printing

3D printing describes the process of creating an object in three dimensions from a digital set of instructions. It is not unlike printing 2D images on paper, except that the printed object is expanded upward in a third direction. 3D printing is most commonly used in additive manufacturing. While there are several other methods of printing or producing parts in three dimensions, such as binding granular materials, photo-polymerization, and various forms of sintering, all of which offer various advantages and drawbacks, 3D printing provides the most economic and fastest-growing area of additive manufacturing. Most 3D printers manufacture parts molten polymer deposition. In this process, a raw feed of polymer is extruded from a fine point onto a support platform or structure layer by layer. Photo-polymerization is used by some types of 3D printers, and utilizes light to cure photopolymers, or polymers that react to light, layer by layer to form a part. Regardless of the method of printing, 3D printers can be applied to make intricate objects that don't need assembly, small scale rapid prototypes, and replacement parts for machines and tools. While a main limitation of current 3D printing is their resolution and speed of the print, it has improved thousands of times in the past ten years, and is improving at an even more rapid pace due to the attention that the technology has received.

1.9.1 History of 3D Printing

The history of 3D fabrication dates back to 1984 and was developed by Charles W. Hull. The theory and function of printers has changed little since their creation. However, since the beginning of the millennium, engineers have expanded printers' functions, simplified and refined printer design, and most importantly, they have expanded the availability of 3D printers enormously. In less than five years, independent and open source designers have taken 3D printers from being a large-business-only rapid prototyping tool to being an accessible commodity and tool for the average household. While the consumer-targeted printers are currently targeted towards more technology-savvy individuals, it will not be long before we see 3D fabricators like those seen in printers being sold alongside 2D printers in consumer electronics stores.

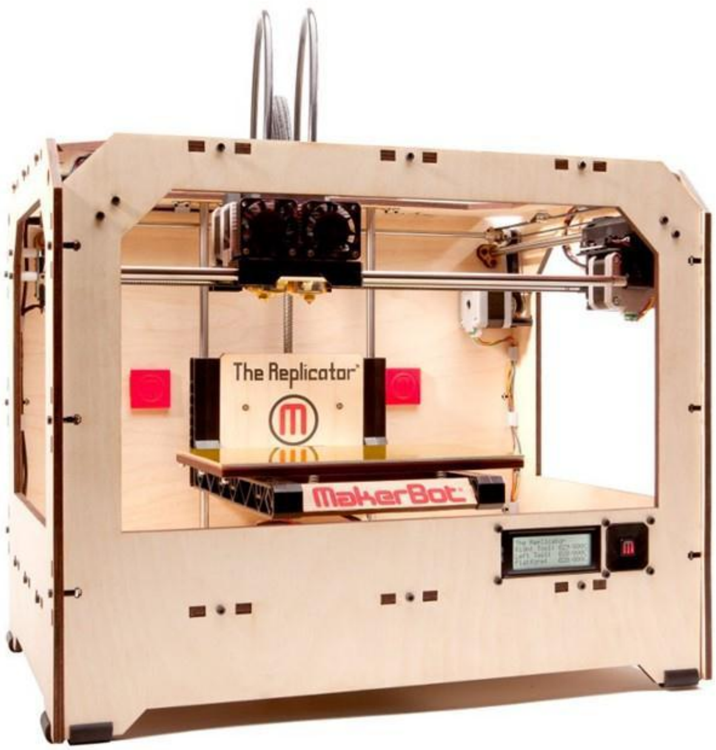

Figure 1.9-1: The MakerBot Replicator is a major step in personal fabrication technology. It provides improved reliability, more options, better resolution, and the largest build area in a personal 3D printer[12].

The hobbyist culture surrounding consumer-level 3D printers has driven a huge wave of innovation in recent years. The movement began with the RepRap (Replicating Rapid Prototyper) Project, which aimed to design and produce open-source designs for a 3D printer that could produce most of its own components on the machine itself. Only seeing major tangible progress in 2008, the project has designed four devices: The original Darwin launch in 2008, the larger Mendel in 2009, a smaller model based off of Mendel called Huxley in 2010, and the simpler variant of the Mendel, the Prusa, designed in late 2010. As the RepRap program gained publicity and visibility online, other individuals began taking the open source concepts and improving upon them. In the time since the Mendel was designed and released, there have been at least ten moderate-to-high profile company startups that specialize in 3D printing. New York City based MakerBot is one of the most well-known companies in the consumer 3D fabrication business, but other competitors such as MakerGear, Fabbster, and Ultimaker are taking the concept behind all of the 3D fabrication designs and making significant improvements in all areas; print resolution, build area, and dimensional accuracy are all being considered and revamped in order to build a better printer.

[12] MakerBot Industries, Fully assembled MakerBot Replicator, http://store.makerbot.com/media/catalog/product/cache/1/image/9df78eab33525d08d6e5fb8d27136e95/t/h/thereplicator

The personal 3D printer is not only being approached by open source and grassroots startup companies. As of January 2012, 3DSystems, the company who acquired Z-Corp in 2011, announced that they will begin launching a personal 3D printer called The Cube, along with an online model store called Cubify that is reminiscent of the iTunes store and Google Play for creating a marketplace for printable 3D models and printed items.[13]

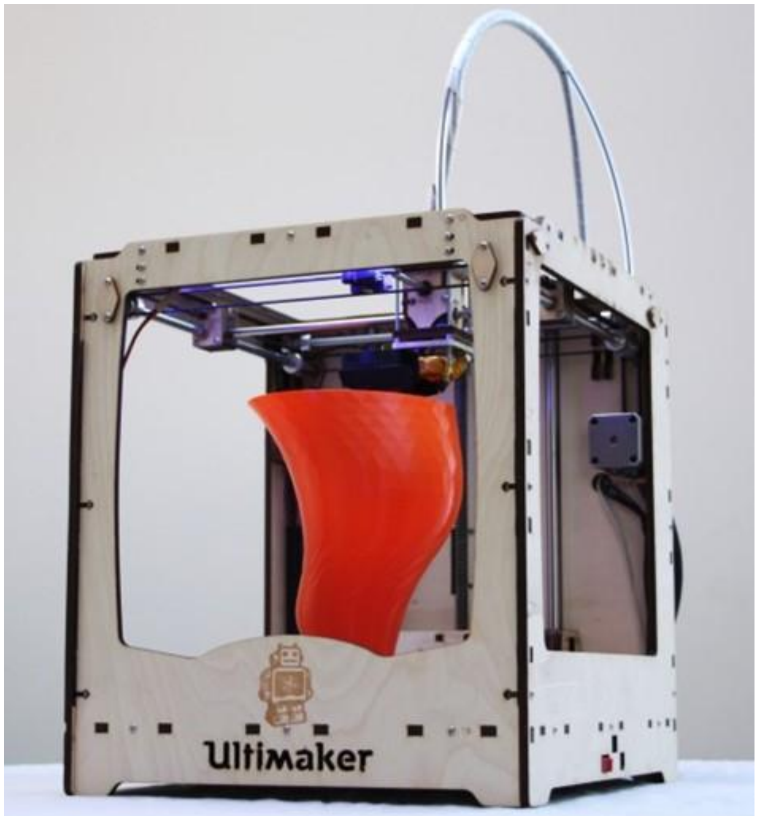

Figure 1.9-2: The Ultimaker exchanges a smaller build area for incredible resolution and customization. The highest resolution prints by any personal 3D printer have been produced from Ultimaker printers[14].

3D printers provide a personal and small scale manufacturing platform that is portable, accessible, open, and serves as a powerful tool for any individual or group looking to manufacture custom parts quickly and cheaply. While these printers use plastic as their printing material, advances in material science and the current polymers available for printing actually exceed the requirements many applications of the parts that are printed. The opportunities 3D printers afford are endless; schools can use them to teach introductory courses in manufacturing; families can produce most common tools and utensils; most importantly, 3D printers provide a cheap and effective platform on which

[13] 3D Systems Debuts First Consumer 3D Printer," 3D Systems, January 9, 2012, http://www.3dsystems.com/press-releases/3d-systems-debuts-first-consumer-3d-printer.
[14] Ultimaker, Ultimaker 3D Printer, Photo, https://shop.ultimaker.com/media/catalog/product/cache/1/image/800x6

young creative minds can physically realize ideas and concepts. These outcomes will promote a society driven not by the consumption of mass-produced goods, but will instead create a culture in which we produce open ideas and customize them to our needs. Creativity and collaboration will grow accordingly, and science and industry will be spurred forward.

Currently, consumers have a broad range of desktop and personal 3D print- ers available to them. From the $500 homebrewed PrintrBot that rose to success and prominence through Kickstarter to the $4000 3DTouch printer by 3D Systems that has been developed and promoted by a large corpo- ration with roots in industrial rapid prototyping, there are an enormous variety of options that consumers can choose from. The most prevalent in the public's eye is NYC-based MakerBot. Having received coverage in the New York Times and on CNN, the small company has been paving both the technological and social roads for the up-and-coming industry.

Figure 1.9-3: Low resolution print of Yoda bust test model printed on early model Ultimaker using stock software packages[15].

The New York Times has covered everything about MakerBot, from an info-graphic centered feature article on the existence and function of MakerBots products[16] seen in Fig. 2.6, to a much more informal blog posting that highlight the release of the MakerBot Replicator[17]. They even wrote a lengthy print article on the innovation that 3D printing

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[15] Centre for Educational Innovation & Technology, Yoda Bust Print of PLA Plastic, Photo, http://ceit.uq.edu.au/system/files/news/yoda.jpg.

[16] Frank O'Connell, "A Machine That Gives Shape to Your Ideas," *The New York Times* (New York, NY), September 14, 2011.

[17] Nick Bilton, "Makerbot Introduces Larger, Two-Color 3-D Printer," *Gadgetwise - The New York Times*, January 10, 2012, http://gadgetwise.blogs.nytimes.com/2012/01/10/makerbot-introduces-new-larger-

encourages and the possibilities and accessibility that the new generation of tools provides. The article, built primarily around quotes and stories from avid users, paints a picture of the creativity, the unbridled freedom, and the collaboration that the new technology enables and encourages[18]. The slew of articles from the New York Times is not entirely surprising, as the short article by Frank O'Connell mentions that the New York Times Company is an indirect investor in MakerBot Industries[19]. It is still clear that the Times' coverage of the company and their developments has helped 3D printing technology gain public exposure and support. However, while the small subculture that has developed around 3D printing is spurring forward social developments, there is another side to the rise of the personal printer: big business.

Figure 1.9-4: High resolution Yoda bust printed on a late-model Ultimaker printer with advanced and modified software[20].

Putting personal printers in the hands of individuals creates the potential for eliminating the need for large manufacturers and supply chains for simple (and not so simple) products. Why would a consumer buy a product at the store if they can print it at home and customize it to their personal needs for a fraction of the cost of the store-bought part? Johnny Ryan, a senior researcher at the Institute of International & European Affairs and author of A History of the Internet and the Digital Future, contributed an insightful article to CNNs Fortune & Money publication that presents the idea that large manufacturing for simpler objects will become a function of the past. For the end user, this ultimately produces a better experience due to a decrease in cost, an increase in availability, and the fact that designs of common products will be continuously improved upon by countless

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two-color-3-d-printer.

[18] Melena Ryzik, "3-D Art for All: Ready to Print," *The New York Times* (New York, NY), May 13, 2011.

[19] O'Connell, "A Machine That Gives Shape to Your Ideas".

[20] Dave Durant'sBlog, 60% Scale Yoda Bust Print, Photo, http://i.imgur.com/rmZGK.jpg.

individual[21]. The crowdsourcing development model is one that has been seen in the open-source development of consumer 3D printers themselves, and has spurred forward more advances in less than 5 years than have been accomplished by corporations in the same field over the course of 28 years. This same phenomenon is starting to propagate itself through the open source models hosted on community repositories like Thingiverse. Ryan also cites a research firm who predicts that all 3D printing related sales equipment, materials, and services will increase from $1.2 billion to $5.2 billion in just ten years[22].

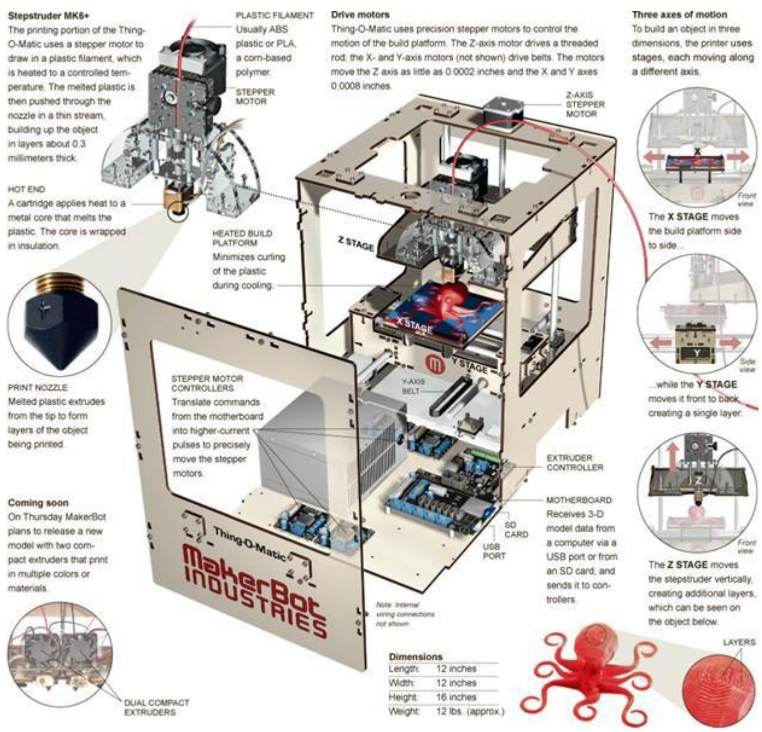

Figure 1.9-5: Expanded infographic of the MakerBot Thing-o-Matic, detailing its function as well as its different features and capabilities[23].

Another important point raised by Ryan is that the new open-source market for models and parts online creates a questionable atmosphere for copyright infringement, intellectual property theft, and counterfeiting. At the beginning of 2012, the infamous and world-renowned piracy site The Pirate Bay launched a category of downloadable content referred to as physiables, or physical objects. In their release blog post, they comment how the future of society lies in digitally created objects being transformed into physical form a 180 degree shift from taking analog media and transforming it into a digital

[21] Johnny Ryan, "Manufacturing 2.0: The rise of 3-D printers," *CNN Money*, May 23, 2011, http://tech.fortune.cnn.com/2011/05/23/manufacturing-2-0-the-rise-of-3- d-printers/#more-60036.
[22] Ibid.
[23] New York Times, MakerBot Thing-O-Matic Infographic, Photo, http://graphics8.nytimes.com/images/2011/09/15/technology/15basics-web/15basics-web-jumbo-v2.png

form[24]. This has sparked a huge realm of discussion online regarding intellectual property and copyright laws and how they relate to the current and future state of 3D printers. Respected and established technology blog ArsTechnica wrote a three page article on the subject, covering the start of 3D printing copyright battles, the under the radar quality of 3D printing, the differences between open-and-profit-based models of 3D design distribution, and how trademark and copyright could be applied to the industry and the corresponding effects. The most poignant topic discussed in the article is the necessity for a dialogue between the websites like Thingiverse who host the content, and the copyright holder[25]. While we may not be able to print out a pair of shoes just yet, it is important for standards to be established through a dialogue that satisfies most of everyone's needs before regulations surrounding 3D fabrication and 3D design overall becomes too strictly or leniently policed. For an even more in depth examination of the topic, Public Knowledge, a consumer-focused group that seeks to maintain the open access to knowledge pertaining to copyright and technology, pub- lished a whitepaper in 2010 titled It Will Be Awesome If They Dont Screw It Up: 3D Printing[26].

Mars provides two major tests for 3D printing: its adaptability to unknown events, circumstances, and conditions, and its overall ability to provide the necessary parts in a situation where traditional supply lines are removed.

1.10 Martian Resources

Life on mars will be impossible without a supply of resources. Martian settlers will require a range of products that include everything between building supplies and eating utensils. Fortunately, Mars provides an excellent environment and an incredible wealth of resources for producing the materials required for living successfully on Mars. The atmosphere contains an abundance of carbon dioxide and nitrogen, and salt, water, gypsum, silica, alumina, and magnesia can be harvested from the Martian regolith. Subsequently, through the application of electricity, molecular hydrogen and oxygen can be obtained from the electrolysis of water. All of these materials can be used to produce unsaturated polyester resin, polystyrene, glass and glass fibers, and many more polymers with the right chemical processing. While a wide range of materials can be made from existing resources, they cannot be produced without some supplies carried from earth. Catalysts are at the backbone of any efficient reaction system, and polymer production on Mars is no different. According to Crossman and Milligan, 15 catalysts need to be imported from earth to allow for these materials to be made. Not only are catalysts required, but a large chemical plant, or multiple plants, will need to be built to process the chemicals. This is a vital step, because the size and abilities of the plant will determine

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[24] Evolution: New Category, "*The Pirate Bay*," January 23, 2012, http://thepiratebay.se/blog/203.

[25] Peter Hanna, "The next Napster? Copyright questions as 3D printing comes of age," *ars technica*, April 2011, http://arstechnica.com/tech-policy/news/2011/04/the-next-napster-copyright-questions-as-3d-printing-comes-of-age.ars/1.

[26] Michael Weinberg, "It Will Be Awesome If They Don't Screw It Up: 3D Printing, Intellectual Property, and the Fight Over the Next Great Disruptive Technology," *Public Knowledge*, November 2010.

what polymers can be produced and how quickly and efficiently these materials will be made. The chemical plant on Mars will be smaller than most found on earth, but more varied in its components and reaction pathways. This is a function of deriving polymers from an organic synthesis route rather than the traditional fossil-fuel-byproduct system we currently use on Earth. The full reaction pathways for all initial chemicals, intermediates, byproducts, and final products can be seen in Fig. 7. However, Crossman points out that there has been no research or experimentation into the actual design of the plant in relation to the needs and requirements that Mars would present; this is a key area in which further effort is needed if Mars is to be successfully settled.

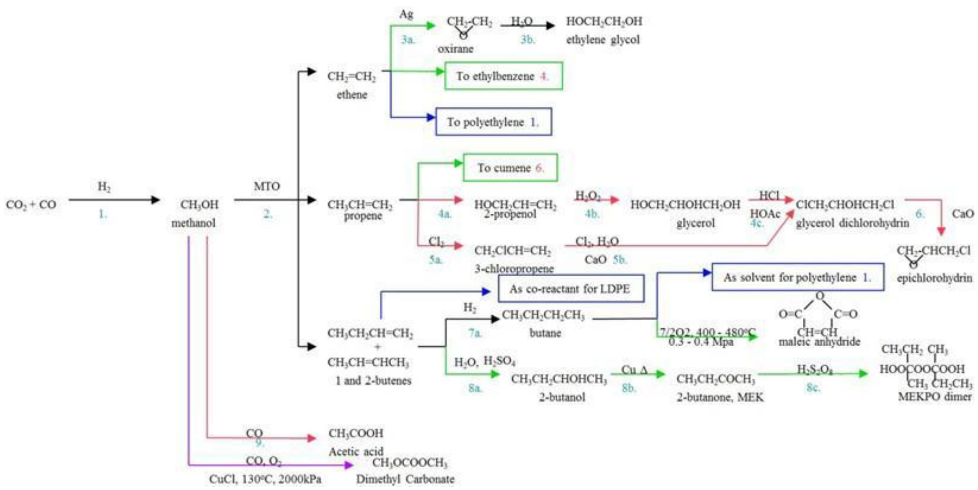

Figure 1.10-1: Reaction pathways for the organic synthesis method of production of polyethylene[27].

Producing polymers on Mars is not only vital to the establishment of a livable settlement on the planet, but it is also a cornerstone for sustained life and for the advancement of both the global and extra-global community. The plastics produced are among many that can be used in a 3D fabricator to produce any component required. The wide variety of materials available for production will mean that settlers will be able to utilize the right material for the job when producing a part. The options for printing will be almost endless. The inhospitable climate of Mars will make the Red Planet inhabitable after all.

Beyond the ability for Martian settlers to be self-sustaining, the resources on mars will play an enormous role in the future of the human economy. Besides his contributions to polymer science, Frank Crossman has also analyzed how Mars could serve as a frontier world, serving as the first of many extraterrestrial trade ports that he describes as analogous to the Britain-Americas-West Indies trade routes of the 18th century. The flow of goods from earth, low earth orbit (LEO), mars, asteroids, and the moon can be seen in figure 2.2.

[27] Frank Crossman and Robert Milligan, Aliphatic Organic Synthesis Sequence, Image.

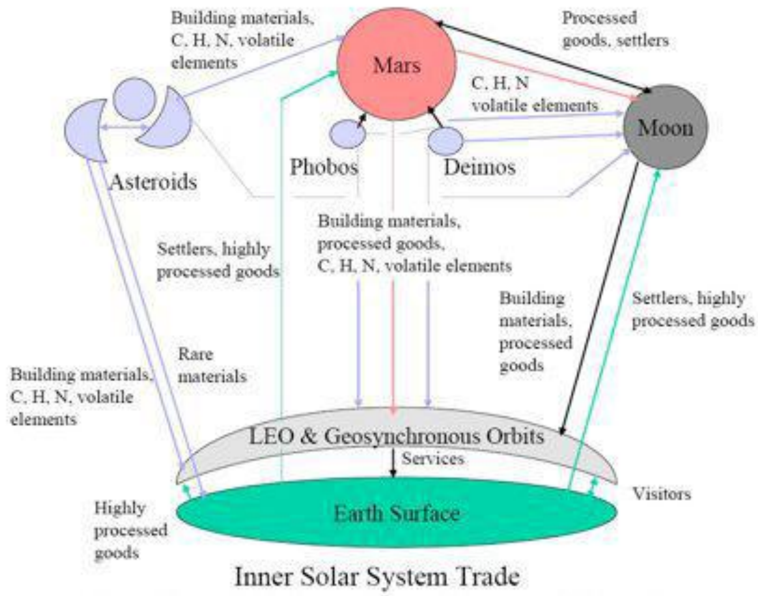

Figure 1.10-2: Inner Solar System Trade between various extra-terrestrial colonies[28]

However, one of the largest challenges for this endeavor is cost. In his presentation for 4Frontiers, Crossman proposes tourism as the solution and impetus for overcoming the financial barrier we currently face. While his observations were made and recorded in 2007 and some of the goals that were set forth to have been achieved at this point have yet to pass, many of the ideas he presents are still viable. The economics revolve around the age-old concept of supply and demand: as the demand for trips into space goes up, the supply will have to increase, and the cost will ultimately go down. Participants will pay for the cost to bring them and their belongings for the trip into space. Crossman estimates this would be about $300,000, on average, to start. However, the tourism companies will need supplies for each participant, which adds another estimated $300,000 per person. The high cost is due to the materials required to bring a given amount of weight from earth into orbit. But what if the need to break from the gravity of Earth was eliminated? Crossman investigates the idea of importing goods such as food from Mars into LEO. By taking advantage of the gravitational fields in our solar system, the cost of transport for the same amount of weight can be reduced by half if imported from the red planet. This LEO space tourism would create a market that would ultimately pay off and improve upon the $30 Billion investment it would take to establish the first settlement on Mars, and will help to make life on and around earth even more prosperous. As Crossman stated, “Mars Needs People and Tourism”; it is the gold-rush frontier of the future[29]

[28] Frank Crossman, Inner Solar System Trade, Image, Building a Self-Sustaining Permanent Settlement on Mars Presentation

[29] Frank Crossman, Building a Self-Sustaining Permanent Settlement on Mars, 4Frontiers, Presentation, http://www.marsfoundation.org/files/IQP-Mars/Crossman_Juniper_8_12_07c.pdf.

1.11 Why Mars

Humanity's home is planet Earth and it is where our entire history took place; it is where we've lived for hundreds of millennia. Humanity as a race has been constantly expanding outwards from lush regions of prehistoric Africa, to the furthest reaches of the planet. This culminated to our first attempt at extraterrestrial exploration to the Earth's Moon in 1969. Unfortunately, the Moon and most of the planets and bodies in our Solar System are not currently viable options for life to prosper. In fact, the only real possibility that exists outside of Earth for seeding a self-sustaining civilization with current technology is Mars. The unfortunate downside to Mars is that it currently resembles a wasteland; its atmosphere can't be breathed as is, and its water is hidden away, frozen under the surface, but this is the best planetary option according to many scientists and engineers. Before justifying the reasoning behind selecting Mars, one must start at the history of space travel to understand how and why humanity must colonize Mars.

1.11.1 History of Space Exploration and Travel

During and after the Second World War in the 1940's, Germany, the United States of America, and the Union of Soviet Socialist Republics developed the technology to deliver payloads at high velocity utilizing the concept of the modern rocket. These rockets were large cylindrical tubes with a chemical propulsion engine attached to the bottom it that made it possible for objects to breach the outer atmosphere and stay in space. It was during this time, that an ideological conflict arose between the Union of Soviet Socialist Republics and the United States of America that had both entities attempting to reach higher ground. The first steps in this "space race" included sending satellites into orbit to understand the concepts of gravity and UV rays. Following these unmanned missions were manned missions into space and orbit, and finally, in 1969 the United States made it to the Moon with the famous Apollo 11 moon landing of Neil Armstrong and Buzz Aldrin. There have since been 5 addition lunar landings, the last one being Apollo 17 in 1972, for a total of 6 human lunar landings.

Nations joined efforts to launch objects into space. These new international ventures were satellites which included the International Space Station where experiments were to be carried out in zero gravity and the Hubble Space Telescope, the largest and most versatile space telescope currently in orbit whose images have allowed scientists to deduce ideas about the nature of space including its vastness, its composition, and how matter is propagated throughout it.[30]

In the 1969 Apollo 11 mission, NASA made its first of many landings on Earth's only natural satellite, the moon. At a distance of about 380,000 km away, it was a feat of incredible heights. The complexity of launching a rocket module carrying astronauts 380,000 km away, towards the moon, getting in gravitational orbit, launching a lunar lander to then then retrieve it and return back safely, was, in every sense of the word, astronomical. The mission to the moon was accomplished with a small fraction of

[30] NASA. *HubbleSite.* 03 01, 2012. http://hubblesite.org/ (accessed 03 20, 2012).

computing power and rocket technology in comparison to the amount of computing power scientific advancement has made available in the last 40 years. In 1969, the most advanced computers on the Apollo 11 mission to the Moon were fairly large totaling about 1900 and 70 lbs. with a 2.04MHz frequency processor. Mobile processors, similar to those found in mobile phones, have more than a thousand times in processing power able to calculate billions of operations per second; with only slightly more other planets could easily be reached.[31][32]

Mars being the fourth planet of our Solar System at a distance of 56.0 million km from Earth is almost 148 times further than the trip from Earth to the Moon. Mars first close-up picture was taken in 1965 by the Mariner IV, NASA's photographic probe attempt at reaching Mars to document the planet's surface. The Mariner IV's close-up showed that the planet had impact craters on its surface which justified continuing the study of Martian surface by the Mariner program into its ninth iteration. NASA has only been able to just recently send autonomous vehicles that gather and analyze information about the planet's surface. For a time, Mars exploration hit a low after 1986 and NASA was left to acquire information through inference or other methods about whether there was ever life on Mars. From 2004 to 2010, NASA also successfully landed the Mars Expedition Rovers, named the Spirit and Opportunity which produced interesting results after analyzing local geology and rock formations.

Mars rocks and regolith (soil) had characteristics of rocks that were heavily in contact with water many years ago; the assumption exists that if Mars had an abundance of water, it may have had life at one point in time which could mean that the planet could be converted into a livable environment. In 2011, sparked by the discovery that was analyzed by the rover data, NASA was able to launch the Mars Science Laboratory (MSL) on the rover named Curiosity. The MSL left equipped with ten times the scientific equipment previous rovers had. NASA scientists are hopeful this information will lead to a manned mission in the near future.

Modern rocketry being produced is beyond capable of providing enough thrust and fuel efficiency to get Martian explorers to its surface. Given our current methods of transportation, it would take 6 to 10 months to get to, or from, Mars and about 400 to 550 days on the surface until the next opportunity presents itself to leave, depending on the year and orbital location of Mars.[33][34]

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[31] Thelen, Ed. "Ed Thelen." *M.I.T. - Apollo Guidance Computer.* 06 00, 2009. http://ed-thelen.org/comp-hist/vs-mit-apollo-guidance.html (accessed 03 17, 2012).

[32] NVIDIA Corporation. "Tegra 2 Specifications." *NVIDIA.* 01 07, 2012. http://www.nvidia.com/object/tegra-superchip.html (accessed 03 20, 2012).

[33] Phillips, DR Tony. "Super Full Moon." *Science@NASA.* 03 16, 2011. http://science.nasa.gov/science-news/science-at-nasa/2011/16mar_supermoon/ (accessed 03 20, 2012).

[34] Zubrin, Robert. *The Case for Mars: The Plan to Settle the Red Planet and Why We Must.* New York City: The Free Press, 1996. pg 79

Mars is currently not hospitable with its unbreathable atmosphere, its lack of liquid water, its environmental hazards, and its lack of radiation shielding. Water can be produced from chemical processes that grant fuel and water as byproducts, as is the case with the Sabatier process, or mined from ice found deep in Mars crust. According to Robert Zubrin, in his book The Case for Mars, Mars is able to be converted from its current inhospitable state to a planet underway to full terraforming, a process that takes thousands of years. Its unbreathable, carbon-dioxide rich, air can be converted to oxygen rich environments using photosynthesis in plants, allowing almost infinite amounts of breathable air for Martian crew members as well as food products from vegetation.[35]

1.11.2 Lunar Alternative

Mars hasn't been the only candidate for colonization it was definitely not the first. The notion of making the moon for a site for a base was described before there was even space travel. In 1638, Bishops John Wilkins wrote *A Discourse Concerning a New World and Another Planet* wrote about the future containing a prominent lunar colony[36]. A more famous science-fiction author Arthur C. Clarke first proposed a method of landing, creating, and maintaining a lunar base including the notion that the moon would need constant commerce with the Earth in order to be successfully maintaining it in a proposal named *Lunar Base Designs*.

Before the complexity of a lunar voyage was fully engineered, the United States Army created Project Horizon in 1959 which detailed the process of getting soldiers on the moon by 1965 including 64 separate launches to get cargo and troop occupation on a lunar base. The purpose for this base would have been the exploration, scientific expansion of the moon, and observation and surveillance of Earth and Space.[37] Project Horizon would have been budgeted at 6 billion dollars in 1966, a paltry sum compared to the 23.9 billion.

Another project of note was proposed by the United States Air Force in 1961 which was similar to the Apollo mission. Its key difference was that the entire spacecraft would land on the moon, rendezvous with a separated crew in lunar orbit before returning to Earth. The major drawback was based around health concerns for the astronauts being exposed to radiation awaiting reentry. Many of the problems based on the difficulty of implementation of these projects were resolved or done away with the introduction of NASA and its Apollo program.

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[35] Zubrin, Robert. "The Economic Viability of Mars Colonization." *marspapers.org.* 1999. http://www.marspapers.org/papers/Zubrin_1995.pdf (accessed 3 20, 2012).

[36] Johnson, S.W. & Leonars, R.S. *Evolution of Concepts for Lunar Bases.* Houston, TX: Lunar and Planetary Institute, 1985.

[37] United States Army. "US Center of Military History." *Project HORIZON.* AMBA (Army Ballistic Missile Agency). April 3, 1959. http://www.history.army.mil/faq/horizon/Horizon_V2.pdf (accessed March 27, 2012).

Advantages and Disadvantages of a Lunar Base

Although often considered for a permanent settlement, the Moon is not necessarily the best option. It has its advantages to other planetary candidates as well as considerable drawbacks. It could be a monetary destination similar to how Las Vegas or the Wonderful World of Disney operates. Basically assuming no responsibility for growing its own crops or making sustainability its primary goal, these lunar economic centers would import all goods and commodities from Earth transport. The idea of privatization of space travel itself has already become a reality when in 2001, Dennis Tito became the first fee-paying space tourist to visit the ISS (International Space Station). Each trip the Apollo missions took averaged about 3 days and 4 hours long with the Saturn V rocket a technology around since the 1960s.

Communication also has its advantages on the Moon. With only a 3 second delay in communication, and with satellites currently in orbit acting as communication relays when line-of-sight communication is not possible, communication is relatively fast. This time delay is simulated in current telemetry-based operations of radio controlled platforms by issuing commands with the inherent 3 second delay. Time lags are further reduced when the Moon is closer to the Earth as well with the introduction of more satellites to act as relays.

The Moon's orbit is potentially useful in and of itself when it comes to space observation and exploring. An observatory placed on the moon would increase the maximum visual distance a telescope would be able to photograph, because observational lenses and scopes placed on the lunar surface have the benefit of lack of atmosphere that would otherwise interfere with image collection. Its orbit and lack of atmosphere also lend itself to being a prime candidate for launches to other locations around the system, be they asteroids or planets, reducing the amount of fuel needed to make the journey normally from Earth.

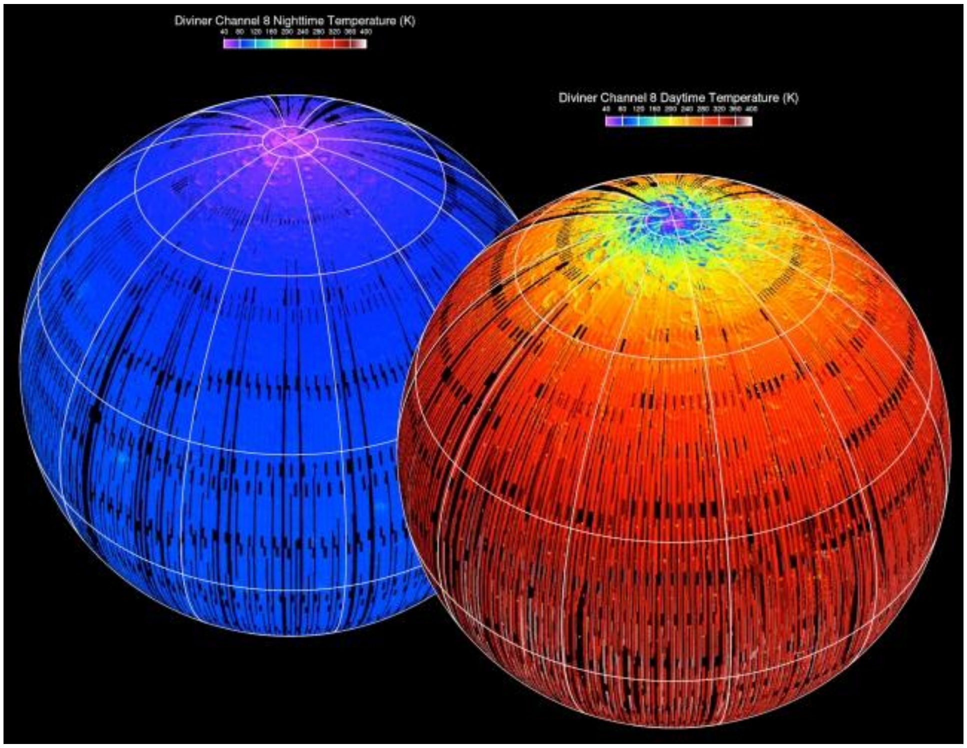

Figure 1.11-1: Lunar Heat Map. Picture Credit goes to NASA

The benefits of having a lunar base are quite present and they would provide a commercial benefit as well as a scientifically practical one. However, when talking about maintenance and autonomy, the moon and asteroids suffer a major disadvantage against planets with atmospheres. Specifically, the Moon has very little Carbon, Hydrogen, and Nitrogen meaning the atmosphere has to be made available on a surface settlement, and terraforming would not be a viable option.[38] There are large temperature extremes on the dark side, and light side, of the moon that would be hazardous for any human being caught outside any lunar shelter.

These temperatures range from 127^0 C during the day and -150^0 C at night just along equator. Solar power may be desirable to power a lunar settlement, however, solar power would not be available at all times because at almost all locations on the surface of the Moon are covered in darkness during half of the time during lunar rotation.
If nuclear power is used to power a lunar settlement, it may be very difficult to radiate away the waste heat during the 14 day period of continuous sunlight which heats the area.

Health effects on human beings, as well as other organic life, are a major concern for living on a lunar base. Gravity on the Moon is one-sixth that of Earth's, and it is known that the effects of weightlessness on the human body include bone and muscle mass

[38] NASA. *Lunar Prospector.* October 2, 2001. http://lunar.arc.nasa.gov/index.html (accessed 03 27, 2012).

deterioration and a depressed immune system, unfortunately most testing has been done in zero gravity and not much is done in one-sixth normal gravity.[39] Its lack of atmosphere above the lunar surface does not protect against solar flares, radiation, or meteors which are an extreme health hazard for any organism. The effect a lunar day-night cycle would have on plant life could be detrimental to its growth and crop yield considering that there is a 354- hour light cycle and a 354-hour dark cycle on any part of the lunar equator. This light-dark cycle would have to be used to its fullest amount if plants are to survive on the surface, otherwise these plants will receive too much light and burn out, or too little light and wither away.

These considerations make it difficult to foresee a permanent lunar installment especially since it would have to be dependent on Earth's resources without much production to shore up its own stock and resources. The constant resupply of a lunar base would be costly in supplies as well as fuel and leaving the Earth's atmosphere is very fuel intensive. The utility of a lunar settlement could outweigh its dependency, but the lack of any international effort to do so would leave one nation to pay for what would be an extremely expensive venture for little to no return. That is why many scientists and astronomers consider one of the best options to be a Martian settlement.

1.12 Mars Early Expeditions and Resources

A Martian settlement means that each launch has to be carefully calculated and can only be a small number launches per every few years. First thing needed to start a Martian settlement is a Martian exploration.

According to Zubrin, Mars surface expeditions would mostly consist of geological surveying and the search for life, present or past, through fossils. This surveying would lead to the discovery of an optimal location suitable for base deployment that would provide natural shelter from sand storms, radiation, and low pressure storms. The exploration and survey team's objective would be to survey the surface and geology of Mars with the purpose finding useful materials in the soil to be later used for research purposes. The survey team would consist of a 4 to 8 man crew of scientists and engineers dedicated to finding enough to research and completing all there is to accomplish in the short time frame they would have (about 400 to 550 days).[40]

Mars is filled with resources, but the problem is that they are as difficult to reach as most fuel sources on Earth, such as fossil fuels or coal. However, in the Martian atmosphere alone, there are large enough compositions of the chemicals Carbon-Dioxide[41] used to produce different types fuel usable for propulsion, portable power supplies, and

[39] Vinh Hoi Le Chau, Daniel Hon, and Sebastian Golze. "Humans in Space Introduction." *Astrobiology: The Living Universe.* 2000.
http://library.thinkquest.org/C003763/index.php?page=human01
[40] Williams, David R. A Crewed Mission to Mars... 01 06, 2005.
http://nssdc.gsfc.nasa.gov/planetary/mars/marswhy.html (accessed 03 18, 2012).
[41] (Mars Foundation 2006)

combustion.[42] Nitrogen is pulled from the atmosphere, reacted with hydrogen to form ammonia and is then used as a fertilizer for oxygen producing plants. Argon can be used as a mixing gas in breathable air, to slow down combustion. Silicon is mined from the regolith to produce essential products like solar cells or glass and other structural materials such as fiberglass and resin with the aforementioned Carbon and Hydrogen[43] [44]. Martian resources available to make or synthesize into plastics, such as polyethylene, polyester, and epoxy, usable in production of essential living products, easily printed in a 3D platform.[45] With the ability to produce plastics and fuel, industry on Mars is capable of a thriving economy. If the cost of interplanetary shipping can be reduced as well as a symbiotic relationship with Earth-based commerce said economy will flourish.

The Mars Homestead ™ Project is "an interdisciplinary effort whose objectives include establishing the need for a first permanently inhabited settlement on Mars, develop a design for said settlement, identify […] manufacturing technologies, build a full-scale terrestrial analog, and develop and test the necessary technologies and systems"[46] operated by the Mars Foundation to teach and enlighten naysayers or the uninformed about how feasible and economical a voyage, settlement, and installation of a base on Mars can be. This group well-establishes all materials and disciplines necessary to fully conduct and implement a Mars Direct plan which Zubrin so often calls for.

Zubrin makes the anecdotal claim that living on Mars will provide a sight whose landscapes and atmosphere can only be matched in certain desert locations on Earth whose red landscape would be comparable to that of Mars. He goes on to state that houses will have to be different from the traditional kind seen normally on Earth due to this harsh atmosphere and weather that comes with it. Ideally, Zubrin posits, that houses will need to be flexible, easily fabricated, and durable with enough spatial accommodation allow for comfortable living.

Most of Martian construction is designed to be curvilinear in shape and low to the ground, similar to Roman vaults and arches, and comprised of plastics like fiberglass or as brick made from regolith.[47] [48] They are designed with curved features to withstand

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[42] Planco, James. "Making Mars Relevant." *Spacewatch*, 1992.
[43] Mars Foundation. "Mars Homestead Polymers PowerPoint Presentation." Marshome.org. 2005. http://www.marshome.org/files2/MarsHomestead-Polymers.ppt (accessed April 30, 2012).
[44] Mars Foundation. "Mars Homestead Project - Gas Plant." MarsHome.org. 2006. http://www.marshome.org/files2/MarsHomestead-GasPlant.ppt (accessed April 30, 2012).
[45] The Mars Society Winnipeg. *Plastics.* 2010. http://chapters.marssociety.org/winnipeg/plastics.html (accessed 03 18, 2012).
[46] Petrov, G., B. Mackenzie, M. Homnick, and J. and Palaia. A Permanent Settlement on Mars: The Architecture of the Mars Homestead Project. Technical Paper, SAE Technical Paper, 2005-07-11
[47] Mackenzie, Bruce. "Homesteading Mars." American Society of Civil Engineers. NY, NY: American Society of Civil Engineers, 1988. 465-479.

internal air pressures and their canopies are soil laden to provide adequate shielding from harmful levels of solar radiation in between structures.

Going outside of the habitat requires environmental suits not unlike the Skylab A7L EVA suit or the suits NASA astronauts used on the moon. The suits not only to be need to be pressurized and sealed to maintain breathability. They also must be rugged to withstand abrasion with the soil while walking, occasional falls, all joints must withstand the dust. They must protect against the extreme cold if used at night, and overheating when the person is exercising. Plus the suits will need ventilation, life-support such as CO2 scrubbers, radio communication, and power.

Essential buildings perpetuate living conditions on Mars. An example of an essential building is a greenhouse whose purpose is to grow oxygen-converting plants and vegetation that are also used for consumption. If the settlement is going to be self-sustaining, there should be mining or excavation operations for extracting materials from the regolith including materials used in the manufacture of plastics as well as the water in permafrost form trapped under the terrain. The production of plastics would allow for the manufacture of home-printed 3D objects usable in many different applications including creating parts for the day to day use of a thriving society. Most of the rest of what could be done as a settler of Mars is up for the future to decide and what a future it will be.

2. Methodology

2.1 Exhibit Design

2.1.1 Initial Design Concepts

When we created our first concept of the exhibit, we were focused on the information we were presenting and not on the methods of presentation. The initial design was also based heavily off of the Mars Foundation's existing activities and exhibits, which are not suitable for an installed exhibit display like we envisioned. Despite our lack of understanding about exhibit design at this point in the process, our work in these stages gave us a significant volume of material from which to pull down the road; the original major sections of polymer manufacturing, 3D printing, and mars settlement and habitation acted as guides for our future work. While our initial concept was based almost exclusively in conveying a volume of information, we were able to use the volumes of information discovered and later apply it through the lens of an exhibit designer to create a much more engaging, effective, and interesting exhibit.

[48] Bruce Mackenzie, "Building Mars Habitats Using Local Materials" "Case for Mars III" conference proceedings, AAS 87-216, vol 74, page 575

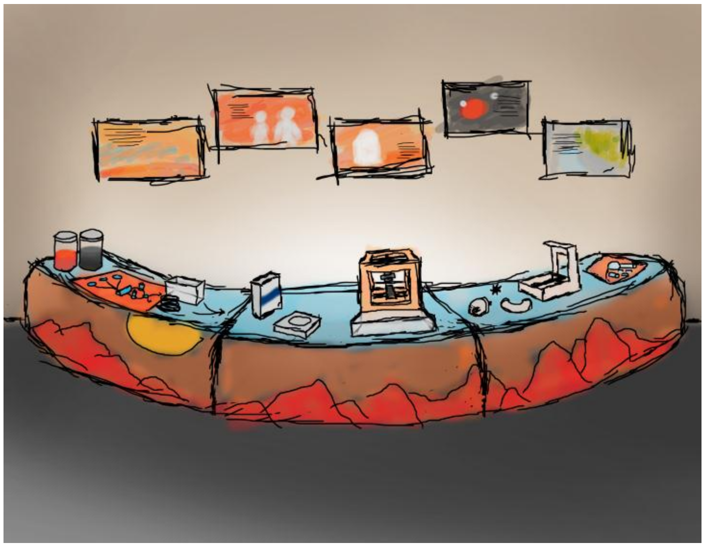

Figure 2.1-1: Original exhibit concept drawing.

2.1.2 Modeling the Initial Exhibit Concepts

In order to visualize the original exhibit design, we converted our 2D concept drawings to 3D CAD models. To begin the design procedure, we established an overall scale for the exhibit. By looking at what we would have available at exhibition shows we set eight-feet-per-section as our main dimension. All other parts were scaled around this. The modeling of the exhibit provided many benefits. Most immediate was the benefit that it allowed us to visualize the physical layout and appearance of our project. The renders also provided us with very nice visuals to use on the website and any other piece of visual communication. However, it wasn't long until we realized that we will be able to use the models to print large portions of the exhibit. This required revisiting all the models to ensure they were to the standards required by the printer. An overview of the materials processing section can be seen in Figure 2.1-2.

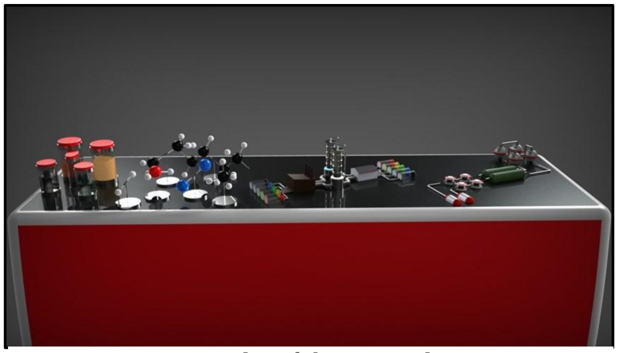

Figure 2.1-2: 3D Render of the materials processing section of the exhibit.

Molecules

The design began with the molecule models. As no team member had extensive experience using CAD software, these simple models provided a good environment in which to learn Solidworks. The beauty of the molecular model parts is that they are derived from common models, so they provide a way for us to streamline and easily expand the molecular information section. The models can even be scaled down as to produce molecular model kits that could be given to or used by students. The models can be seen in Figure 2.1-3.

Jars

The next pieces that were modeled were the jars that would contain mock Martian materials to show the raw material from which polymers would be produced. These were a quick part to produce in Solidworks, as it is a simple hollow cylinder with a lid. Additionally, the jars did not have to be actually made because printing in clear polymer is not possible, and it would be simpler to use store-bought jars that could be modified to appear more in-line with the exhibit aesthetics. The jars can be seen in Figure 2.1-4.

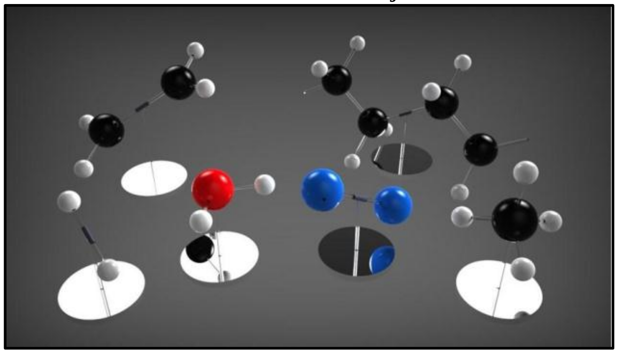

Figure 2.1-3: 3D Render of the molecules portion of the materials section of the exhibit. Counter-Clockwise from lower left: Molecular Hydrogen, Water, Molecular Nitrogen, Methane, Polyethylene, and Ethylene.

Figure 2.1-4: 3D Render of the materials jars.

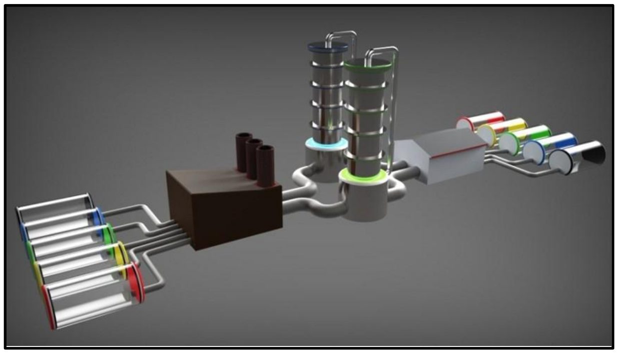

Figure 2.1-5: 3D Render of the earth factory model.

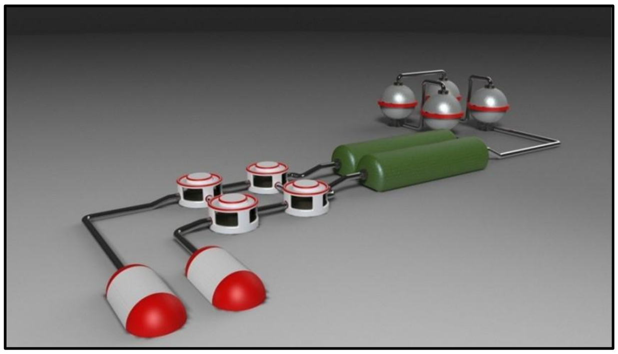

Figure 2.1-6: 3D Render of the Martian factory model.

3.1.7.3 The Earth Factory

The earth factory was a larger scale project, as it consists of eight different unique models, which compose four different assemblies, which compose the overall assembly. Condensing the actual appearance and layout into a simple form that still managed to retain enough information to teach the material was the largest challenge of the earth factory component. This was done by establishing the major steps found in terrestrial factories and representing them with one single building that could be easily explained to audiences. The details of the processes are not what we aimed to teach, but rather the overriding concepts behind the process. The earth factory model consisted of raw material tanks, a factory building for refining raw materials, a reaction section for producing products, a warehouse for processing raw product, and storage tanks for holding finished products. The earth factory model can be seen in Fig. 2.1-22.

3.1.7.4 The Martian Factory

We had a lot of freedom with the Martian factory. There are no concrete design plans for a Martian factory, so the aesthetic design was focused more towards making a display that was eye-catching and that the audience would become interested in. The Martian factory is only made of four major assemblies, and is overall simpler in design than the earth factory. We attempted to implement the concept of reusability that would be required during actual polymer processing on Mars. This is the idea that one reactor or piece of equipment can be used in many different processes that lead to different end products. We did this by using multiples of the same part in the overall model design. There are no specific functions assigned to each of the components, but this is part of the way that the idea of adaptability will be shown; one factory setup can be used for multiple different processes. As with the earth factory, the factory has been scaled down and condensed to save on space and to make explaining and teaching concepts simpler. The Martian factory model can be seen in Fig. 2.1-7.

2.1.3 Meeting with Matthew Martin

Thanks to the connections of our sponsor, we had the fortune of meeting with a professional exhibit designer, Matthew Martin. While Bruce Mackenzie has served as an authority on information pertaining to Mars, Matthew provided us with an authority on exhibit design and using it to convey information and teach visitors. Over the duration of the four-hour meeting, we had our current work – the concept art and CAD models – critiqued, were given advise and brainstormed ideas for the exhibit, received an insight into the industry, and finally were given an outline of the exhibit design process. The meeting resulted in a string of creativity and was the primary driving factor in helping us create the framework for an exhibit.

2.1.4 Materials Processing and Polymer Science

Introduction to Manufacturing

As the first section in the Materials Processing and Polymer Science section, the Introduction to Manufacturing presents the primary concepts of using raw Martian resources as materials to make plastics, and from those plastics make usable and functional objects. It conveys the overall process using clearly labeled elements without burdening the viewer with an overflow of detailed specific information.

Figure 2.1-7: Overview of Polymer Science and Materials Processing section intro.

The introductory section begins with three clear boxes that contain substances to represent Martian regolith, Martian atmosphere, and water. The Martian soil can be fabricated from a mix of dyed sand, clay, and charcoal. The water is simply water. Representing the Martian atmosphere visually is a challenge, but if the box is made airtight and there is some vapor that would create a visible smoke inside, that is be the ideal solution. Each of these boxes are be fitted with a mechanism that will simulate motion in the substance within, giving the illusion that the material is being pumped forward though the system. The regolith box can be fitted with a corkscrew, the water box with a circular pump, and the atmosphere box with a circulatory fan.

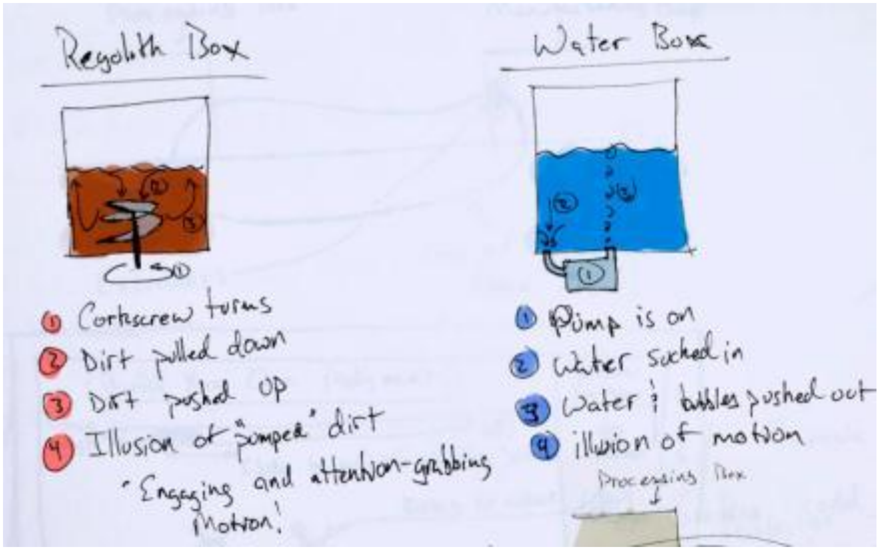

Figure 2.1-8: Raw material boxes and mechanisms for animating them.

These boxes are be connected by pipes into a nondescript "mystery" processing box. A constant steady stream of plastic feedstock used in 3D printers is being fed out of the processing box and into the manufacturing box. This spool is made from the thickest feedstock that is used so that it has a long operational life. It is pulled and pushed forward by a pair of extruder rollers much like the ones used in 3D printers. The spool is fused into one continuous loop so it never requires a manual reset. This part of the introduction to the exhibit represents the transfer of raw plastic material into a manufacturing area that then produces useful items.

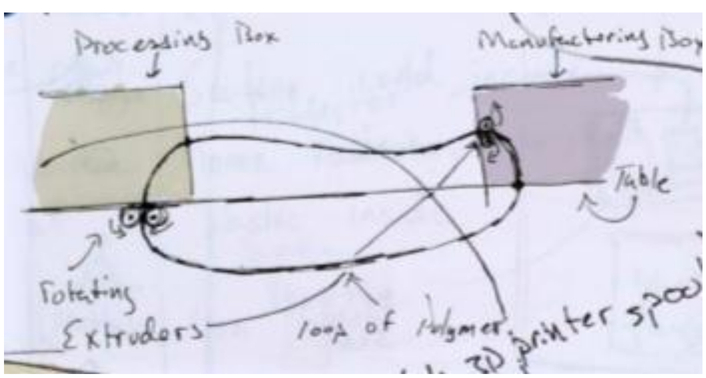

Figure 2.1-9: Perpetually moving polymer strand.

The manufacturing box shows plastic stock being taken into the box and useful parts being taken out. The parts being moved out of this section will be various gears, valves, and larger, more complete tools like hammers and wrenches. They are carried into and through a bin of various parts similar to the ones on the conveyor belt. They are then taken under the table and pulled back up above the table, and out though the manufacturing box again, continuing the cycle. The parts are mounted to the belt using screws or epoxy so that they don't fall off and are able to endure many cycles of operation.

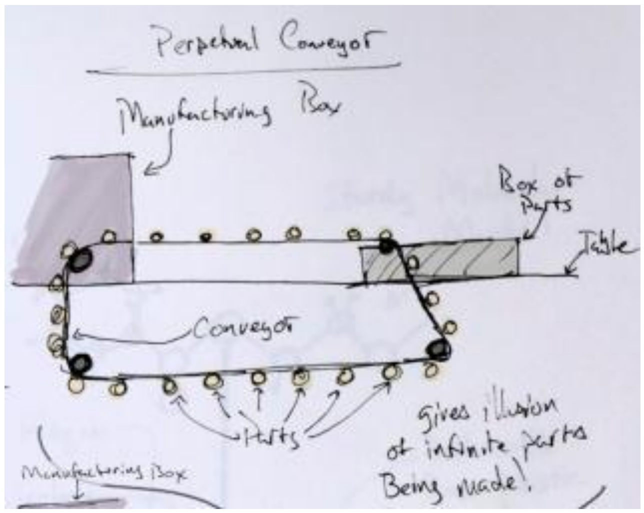

Figure 2.1-10: Perpetual conveyor of 3D printed parts.

Polymer Science

To teach our viewers about polymer science, there are two major components of this section: An interactive "Build Your Own Polymer" game on a touch screen, and a gallery of polymer molecule chains shown next to their products. The first engages and inspires visitors to be interested in polymer science, while the second gives them a real-world connection between the molecules and every-day products they're familiar with.

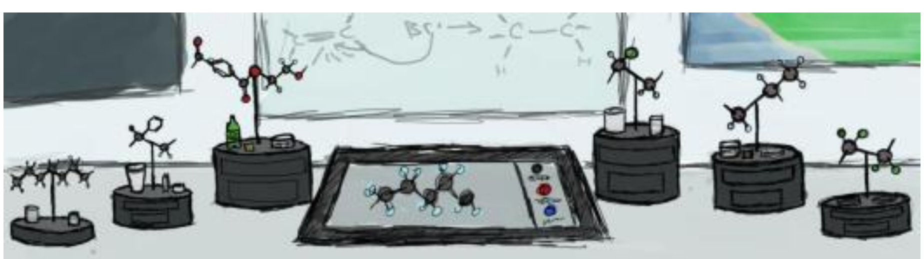
Figure 2.1-11: Polymer Science exhibit centerpiece overview.

The stands surrounding the polymer game display many of the most pervasive polymers in use today. They are built of a base with the polymer acronym, its full name, and its chemical schematic formula. The main visual piece of these stands is the molecular model protruding vertically from the stand. This model shows one "-mer" unit of the polymer. To the right of the model, there is a sample of the polymer in raw form. For polymers that are solid billets in raw form, there is a block the visitors can touch. For polymers that are powder, fiber, or pellet form in their raw state, we have a closed container that holds the plastic. To the left of this portion of the display, there are examples of the real-life uses of the plastic shown in the display. For polymers with common names, there is a list next to the applicable product. Below is an example of one of these displays, depicting PET; this plastic is used in both drink bottles and as the fabric called polyester.

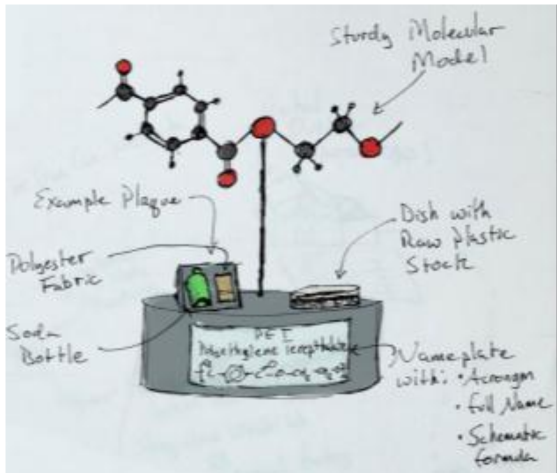

Figure 2.1-12: Detail of model showing model, raw plastic, name, structure, and products.

Build Your Own Polymer Game

The interactive game is on a touch screen computer and is designed to be a freeform creation game for visitors. They are given the opportunity to design their own polymer and learn about the physical properties behind them while they do so.

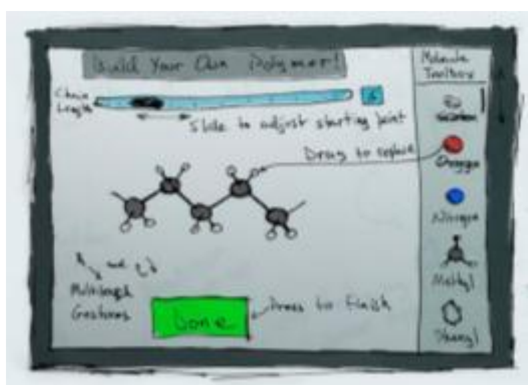

Figure 2.1-13: The "Build Your Own Polymer" game will teach viewers properties of polymers.

The game starts off with a motivational message in the theme of the exhibit. They are told the fields the activity relates to in the real world, while being immersed in the exhibit via a role-playing element while also feeling empowered that they are already “highly qualified for this job.”

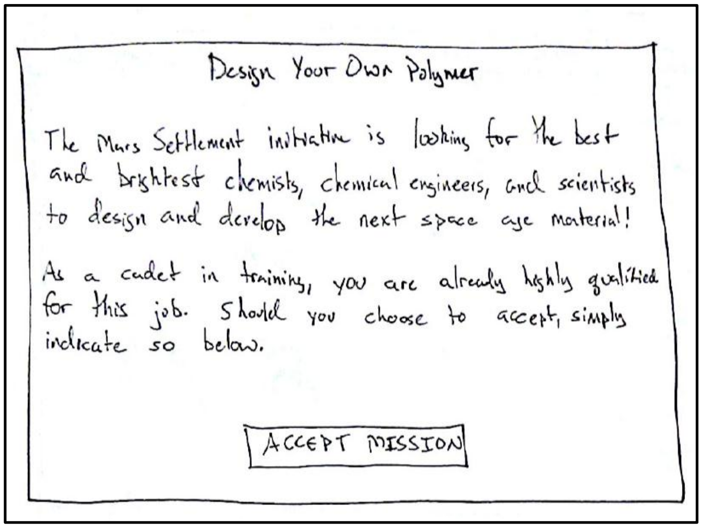

Figure 2.1-14: Build Your Own Polymer welcome screen.

If a visitor chooses to accept the mission, they are given a brief instruction screen.

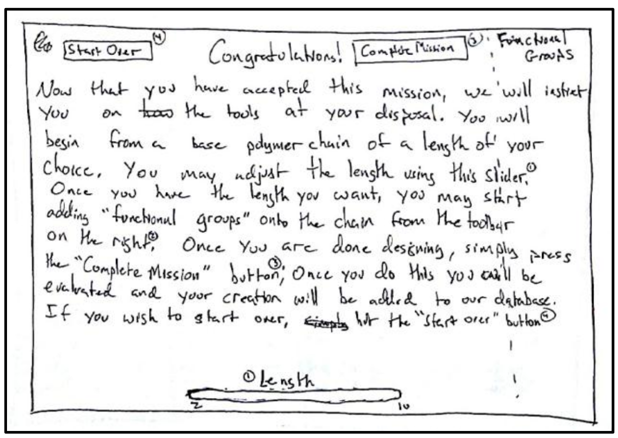

Figure 2.1-15: Build Your Own Polymer instruction screen.

They are given a four-sentence interactive instructional introduction, after which they are able to begin designing their own polymer. They are told the basic controls and then click "start" to begin the activity. Once they begin, they are shown a screen similar to the one below. It has a starting polymer chain in the center, a slider to adjust the length of the chain at the top of the screen, a toolbox of various functional groups they can add to their polymer, and a "done" button to end the activity.

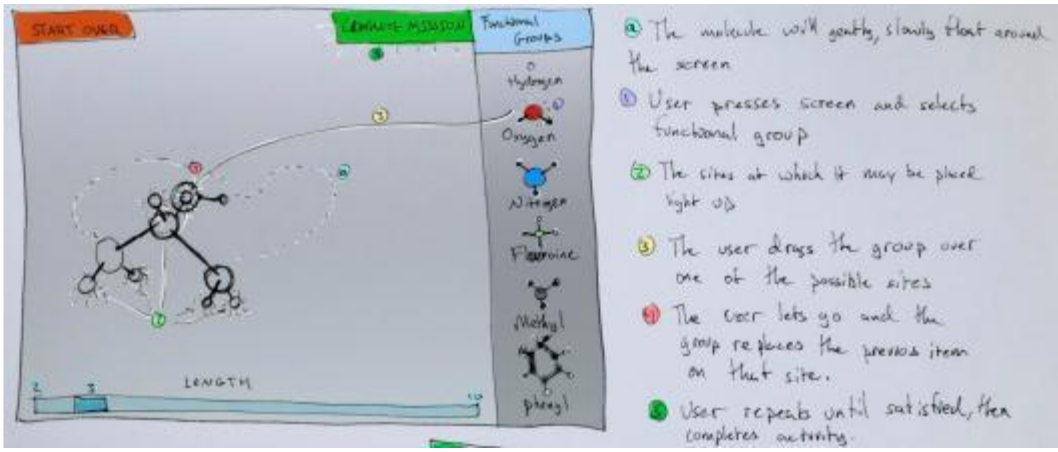

Figure 2.1-16: This is how the Polymer game will function.

The user is able to drag functional groups onto their polymer and see how it changes the structure. They scroll through the toolbox and find a functional group they would like to add to their polymer. To add the group to the main chain, they simply drag it over the main chain, where the groups it can replace become highlighted and the groups it cannot replace dim. Once they are done designing their polymer, they hit the "mission complete" button.

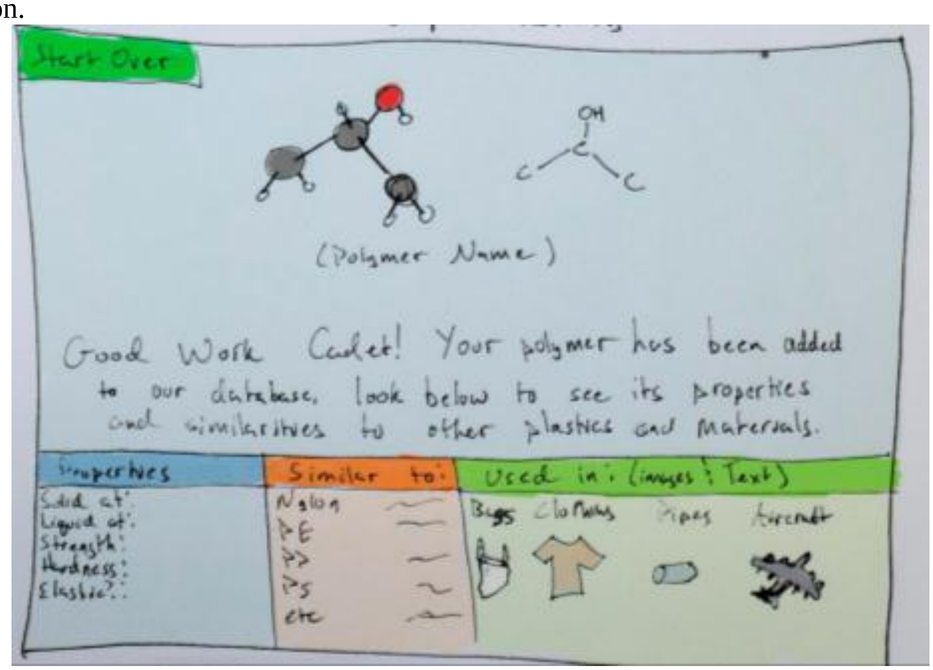

Figure 2.1-17: Polymer Game completion screen.

On the following screen they are congratulated on their success and notified that their polymer will be added to the mission database. They are also presented with quantitative information about the general properties of the polymer they constructed. This takes the form of information such as "hardness", "flexibility", "temperature resistance", "elasticity" and similar qualitative measurements. Alongside this data is a list of several real-world polymers that are similar to the one created by the user, as well as a list of products they are used in, giving the visitor a connection between their own creation and materials they use and interact with every day.

Manufacturing Plastic on Earth

Many of our visitors to the exhibit do not know where the plastic they use every day comes from. To help them understand the significance of plastic in their lives, along with the way in which we are forced to produce it here on earth, we have a three-dimensional info-graphic to teach museum-goers about this process.

The process begins with a miniature model of an oil rig, an oil derrick, and an oil pumpjack, all of which are physically animated. On the flat surface next to each building, there is a name along with a short bulleted list that serves as a description for what each one does and what disciplines are involved with each. By doing so, we are able to teach visitors about more than just mars and engage them on multiple levels making sure that the attention span of more visitors is retained. Dotted arrow-lines run from each of the oil acquisition buildings into a large miniature model of an oil refinery. The refinery is spread out enough that there are labels next to each building such as the catalytic cracker and the fractional distillation columns - both of which are very notable buildings in a refinery. The labels on each building describe in one bullet point what role it plays in refining oil. This way, the learner who is interested in the details of oil refinement can learn about the process, while the individual who doesn't need or want to know about it can simply acknowledge that the oil is refined and move on to the next step. Following the refinery is a chemical laboratory. This lab represents the R&D side of the discovery and development of polymers. It is a simple step that serves to inform visitors of an unsung yet vital aspect of the plastics industry. Following the R&D lab, there are manufacturing buildings for producing the polymer and for processing raw polymer. Again, these serve not so much as an educational tool about polymer science but more to inform the viewer of another vital step. Finally, the path continues to a retail outlet and a home, bringing the process back to a recognizable and relatable center point.

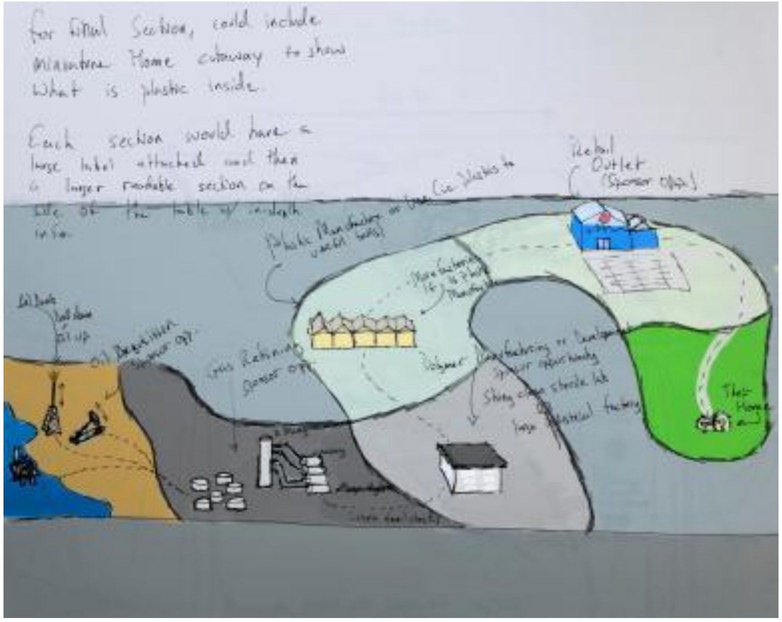

Figure 2.1-18: Where Do Polymers Come From? Infographic/model.

Besides being able to teach students about polymer chemistry and where plastics come from, this portion of the exhibit presents a wealth of sponsorship opportunities in the oil industry, the R&D field, in manufacturing, and to retail outlets. This type of integration with external sources is vital to gain the funding and the recognition necessary for this exhibit to succeed.

Martian Manufacturing

To contrast the process of manufacturing polymers on earth, the Martian manufacturing section of the exhibit shows the beginning steps of how polymers are produced on mars. Due to there being no agreed-upon method for polymer manufacture on mars, we have created an ‘under construction’ zone on a Martian surface with a robotic assembler working to build the first sections of the factory. On the surface of the Mars landscape, there is a diagram of the static reaction pathway Frank Crossman devised to show them the chemistry that has been established. Along the edge of the construction zone are job posting cards that detail the different disciplines that are needed to solve the problem of manufacturing polymers on mars and building the devised facility. The jobs include: chemists, chemical engineers, robotics engineers, aerospace engineers, architectural engineers, civil engineers, and materials scientists. These job posting cards have bulleted lists of required duties, the skills associated with each profession, and the general coursework needed for each. They all have a “cool” factor included in their duties, so that when visitors read the cards they get excited about the “cool” factor and associate that with a “proficiency in math.”

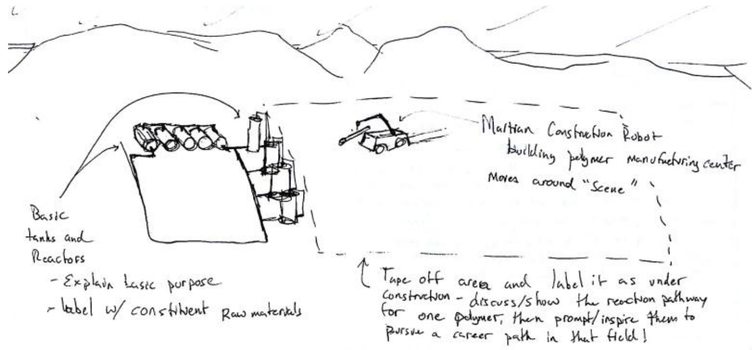

Figure 2.1-19: Making plastics on mars will be a challenging exhibit portion to build effectively.

Build a Mars Habitat Game

This activity is similar to the polymer building game, but it serves tie together many concepts at once. Visitors are shown a scale model of a mars habitat. It is moderately interactive, as they can slide parts of it off to see the habitat inside. The game teaches them how building a proper habitat on mars is vital to survival while presenting them with the challenges faced by the engineers and scientists who investigate these ideas currently. The game functions almost identically to the polymer creation game – they are prompted with a mission, given brief instructions, the actual activity is simple drag and drop, and they are evaluated in an always-constructive way at the end of the activity while being presented with more educational information. The actual activity portion gives them limited resources of metal, plastic, and glass, and a limited time to build the habitat. The resources are to show that polymers need to be utilized due to how ubiquitous they are since they are produced on mars, and to show how limited the use of metal is because of transport costs from earth to mars. The time limit serves to keep the flow of traffic moving at the culmination of the exhibit. The function of the game is as simple as drag and drop; each component has a certain benefit to the crew, but it also has an associated cost. The goal is to build the best and most survivable habitat with the limited resources available. This activity can be expanded into a "plan a mars mission" activity for the full-size travelling exhibit; this would bring all the concepts learned from the 10,000 sq. ft. exhibit together into one activity.

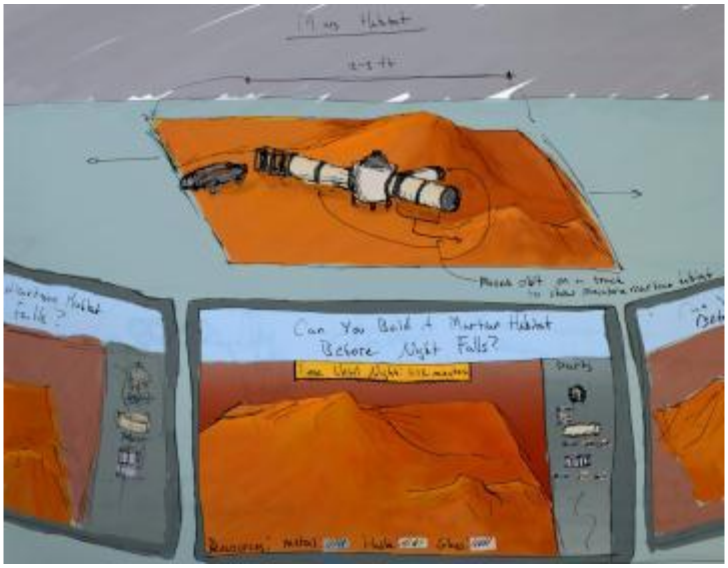

Figure 2.1-20: Martian habitat game and model.

2.1.5 *Fabrication and Design Engineering*

Freedom of Design

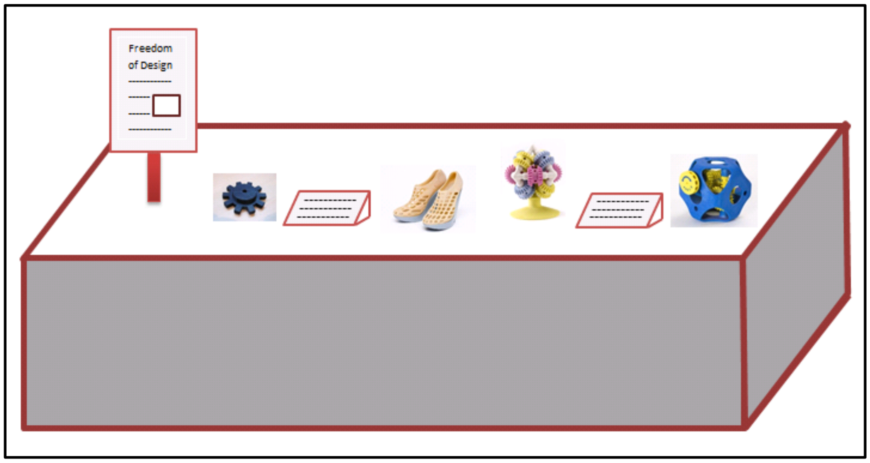

Figure 2.1-21: Concept art of the “Freedom of Design” Exhibit

This part of the exhibit focuses on the vast scale of items that one can make using a 3D printer. Visitors learn about computer aided design (CAD) and its applications to fabrication. This section also displays a wide variety of 3D printed items that range from simple to complex objects. Simple objects include static, everyday items such as utensils, rings, tools, and other simple shaped objects. A 3D printer can print the most complex shapes and designs. It can eliminate assembly steps by integrating moving parts such as gears to the printed part. Several types of complex printed objects are designed to allow visitors to turn, pull, and slide the movable parts.

Fabrication

The purpose of this section is to interact with visitors and show them how easy it is to print an object. Presentations run every 2 hours during the time the museum is open. One to two people are needed to run this portion of the exhibit. The presentation is around 20 minutes long, and discusses topics in basic chemistry, plastic on Mars, 3D printer mechanics, 3D scanning, and terminology. For the finale, the presenter prints out a small object and allows the audience to come up and see the printed part during printing and after the part is finished printing.

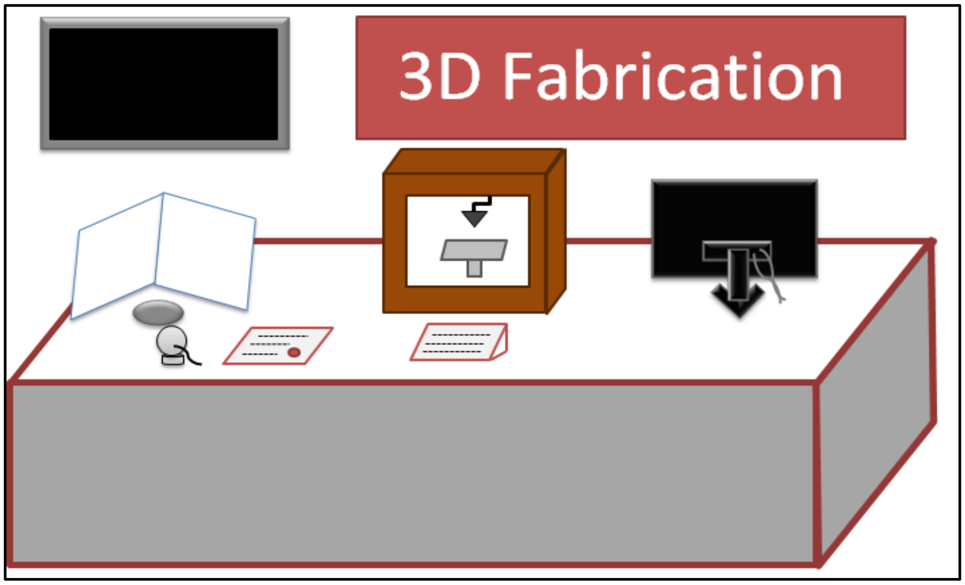

Figure 2.1-22: Concept art for the “3D Fabrication” Exhibit

3D Printer

The 3D printer is the centerpiece of this exhibit. The printer runs only when a presenter is there. Otherwise, it is static and it displays a finished piece laying on the building platform with lights flashing. To keep the hardware and electronics intact, plastic sheets enclose open windows in the printer frame. This is mainly to protect the hardware of the printer from younger visitors who are curious. One side has a key access panel for the presenter to take out the finished object.

The 3D Scanner

A 3D scanner is on display and as part of the presentation. During the presentation, the presenter selects a volunteer from the audience to place their keys on the scanner. The presenter then scans the keys and it appears in the program on the TV screen. It also doubles as an interactive part of the exhibit. Visitors can scan in any object they have. They put the object in front of the scanner on the labeled platform. Then they push the button that says "SCAN." The item is then scanned into the software and appears on the TV screen.

LCD TV Monitors

The monitor displays are set up to mirror what the presenter is showing on his monitor to the rest of the audience. It shows the software for the scanner and 3D printer during the presentation. Depending on location of the exhibit, the TV setup has two options:

1. Set a monitor on the table for the presenter, and a second monitor mounted on a wall or pillar for the audience. This is ideal because it attracts visitors more and is easier for the audience to see.
2. Set monitors back to back on the table. One facing the presenter, the other to the audience

Tactile 3D Printed Part

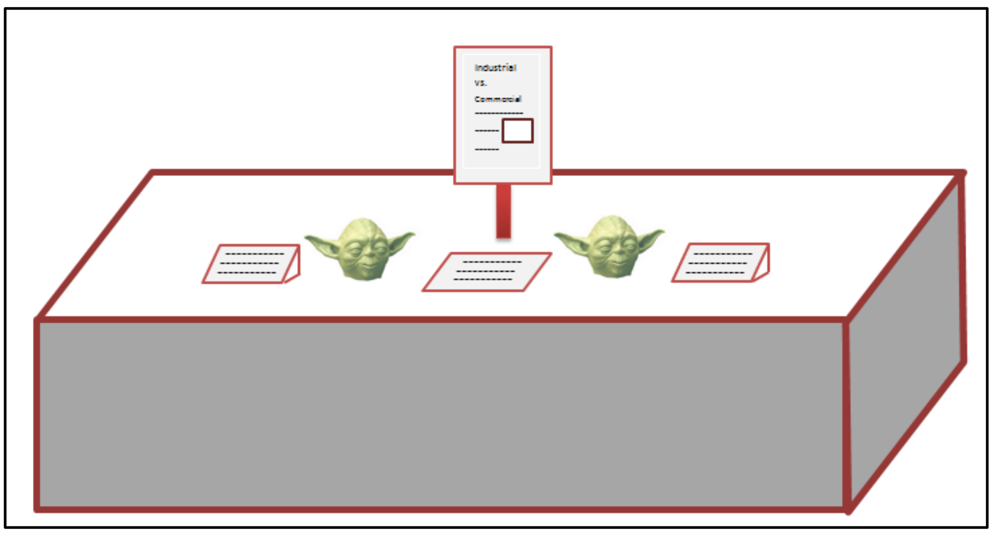

Figure 2.1-23: Concept art for the "Tactile 3D Printed Part" Exhibit

This portion of the exhibit presents the types of 3D printers available on the market. Two Yoda heads are displayed side by side and both have the same dimensions. One is printed from a commercial printer, the other from an industrial printer. Visitors learn the difference between the two different types of printers, as well as compare and contrast price, build area, features and more. They can also feel the two Yoda heads to compare resolution.

Future Applications

There are many things one can do with a 3D printer. But not many people know what to do with one on Mars, or how it can help humans live, grow, and sustain while on the red planet. This part of the exhibit educates visitors on what 3D printers are capable of.

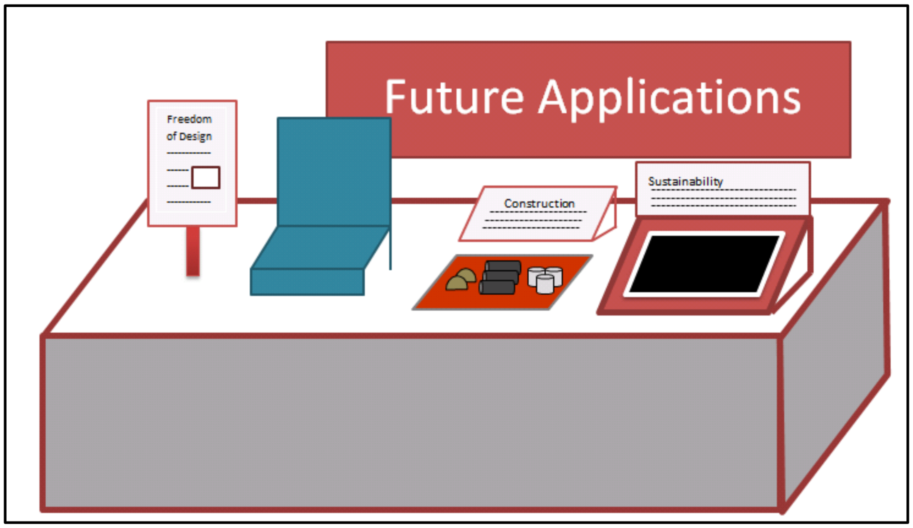

Figure 2.1-24: Concept art for the “Future Applications” Exhibit

Replication

3D printers have the power to self-replicate. Just about anything from a 3D printer can be 3D printed, including circuit boards. This can decrease payload weight for Mars. This portion of the exhibit displays a half completed printer, where its parts have been made from the current one on display.

Construction of Settlement

This portion includes a static 3D model of what a beginning settlement would look like. It also has text and pictures to explain how construction on Mars would be done. It also tells visitors how the use of 3D printers can help build sections of the Mars settlement. It can make furniture, small structures, floor tiles, cabinets, and so much more. Pictures and the model are artist renditions of futuristic structures on Mars.

Sustainability

Getting to Mars is expensive. There is also a time restraint on when to travel to Mars. An opportunity comes once every two years. Not to mention it can take another 6 months to travel from Earth to Mars. This is because Mars and Earth have different orbital patterns. So when living on Mars, humans must live off of what supplies they have and Martian resources. For this portion of the exhibit, a touch screen displays an interactive activity that challenges visitors to survive on Mars. The game has a similar playing style to The Oregon Trail, but more condensed and shortened. Visitors must budget their money and pay attention to their total payload weight. Currency is in dollars. Visitors can purchase how much of one resource they want to take to Mars by simply pressing on the button with the labeled resource. They do this until they have reached the maximum weight for the payload or they have run out of money. Then visitors press the "Launch" button to send their rocket to Mars. Then once on Mars, they begin to use the resources they brought with them to collect Martian resources to sustain themselves. Throughout their time on Mars, visitors are then given a series of questions with multiple choice answers. The visitor's survival is dependent on the amount of resources brought with them and collected on Mars as well as their answer to the question.

2.1.6 All About Mars

While walking through an exhibit about colonizing on Mars, it is irrational to assume that each visitor knows all the scientific facts about the Red Planet by heart. This exhibit educates visitors with cool and interesting facts about Mars and presents historical background of the voyages and missions to Mars.

Figure 2.1-25: Concept art for the "All About Mars" Exhibit

Facts and Background

The Facts and Background section educates visitors about the terrain, atmosphere, and properties of Mars. Facts are easy to read and follow with the bullet formatting and embossed font. A photograph of the surface from one of the satellites that orbited Mars is enlarged, showing much of the topography including ice caps, canyons, and mountains. Facts are presented on the left hand side of the photo. Also to engage visitors and curb their curiosity, they can weigh themselves on a scale that displays their weight on Mars. The units of weight are displayed in pounds and kilograms.

Resources

This section provides visitors what resources are available on Mars, like regolith to make plastic on Mars. On the right hand side, the exhibit lists resources that are beneficial to human survival on the planet. It is in the same bulleted and embossed format as the facts section.

Exploration

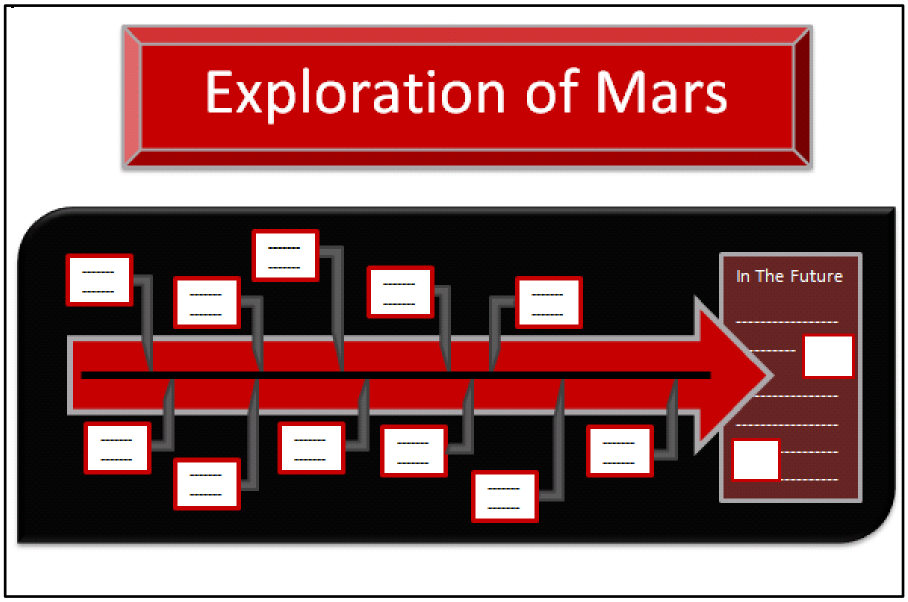

Figure 2.1-26: Concept art for the "Exploration of Mars" Exhibit

Many people do not know that NASA has done extensive amount of research about Mars in the past. A timeline including all the missions to Mars are listed in chronological order of launched date. Each mission is presented with details of type of spacecraft, purpose of mission, and year it was launched to year it was decommissioned. A picture of the satellite/spacecraft is also displayed next to each mission. People also question on how soon there will be a man on Mars. On the right side of the timeline, there is a section that informs visitors on the estimated time of arrival of manned spacecraft to Mars, the first completed settlement on Mars, and the beginning of terraforming Mars.

2.1.7 *Global Heat Map Exhibit*

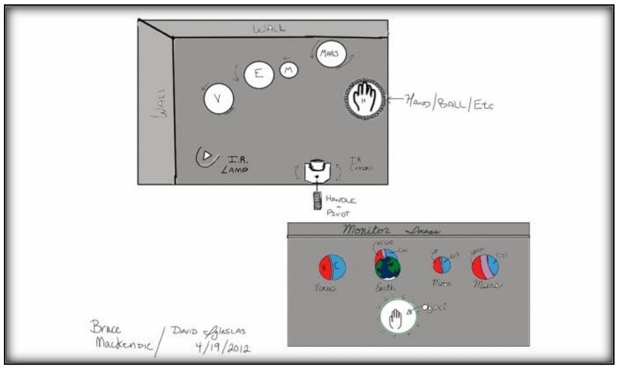

Figure 2.1-27: Global Heat Map Exhibit

This exhibit is part of the Lunar-Martian comparison. This version of the exhibit is of the Lunar globe alongside this is an identical globe with Martian appearance and a third globe with Earth. Each globe is made of different materials or heat sinks that conduct heat at different rates.

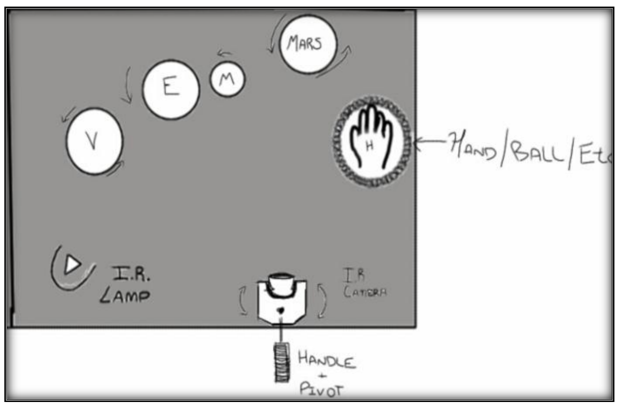

Figure 2.1-28: Expanded globe image depiction

This base of each globe is motorized to simulate the rotations of each planet they represent. The pivot of Infrared Camera is moved manually to achieve different angles on the visual heat maps on the different globes. There is a spot left towards the side, an empty pedestal, on which a large array of objects can be placed. This applies the feeling of action to the exhibit itself. Each child can pass by this move it to see what changes or even stick their hand into the exhibit and look at the monitor to see the difference in temperature.

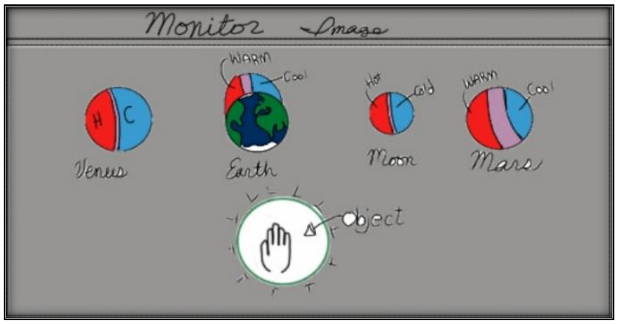

Figure 2.1-29: LCD Screen Concept

The monitor is a normal LCD (Liquid Crystal Display) of any particular size that constantly updates heat information received through a camera lens mounted on the rod that pivots panning the view of the globes. The inspiration for the heat mapping is seen on the right depicting the temperature variances on the moon. This simple design is easy enough for children to read and to understand at a glance without frustrating them or making the relationship between heat and surface unintelligible.

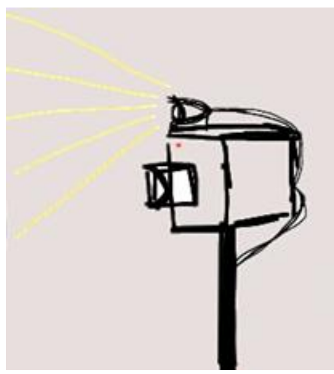

Figure 2.1-30: Infrared Light Camera Combination Concept

This unit is a combination Camera and Infrared light (LED or Incandescent). It functions to emit heat onto the surface of the globe then capture the information to be displayed on the monitor. Its free-moving base allows it to face any point of the equators of the globe it orbits.

2.1.8 Lunar Heat Map Exhibit

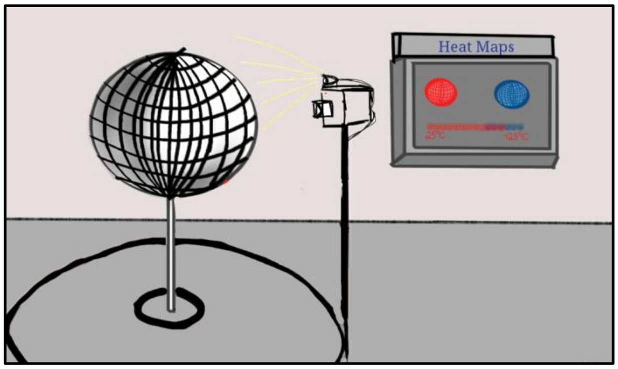

Figure 2.1-31: Lunar Heat Map

This exhibit is part of the Lunar-Martian comparison, a previous version of the Global Heat Map. This version of the exhibit is of the Lunar globe alongside this is an identical globe with Martian appearance and a third globe with Earth. Each globe is made of different materials or heat sinks that conduct heat at different rates.

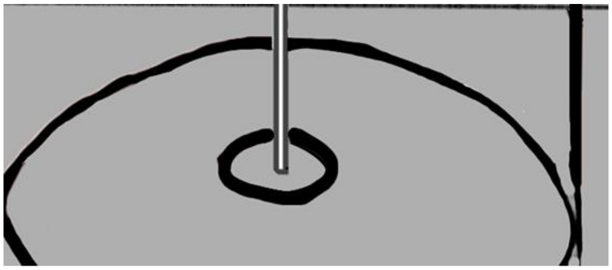
Figure 2.1-32: Lunar Rotational Base Concept

This base is not actuated or motorized in any way. Each rod is moved manually to achieve different angles on the visual heat maps on the different globes. This applies the feeling of action to the exhibit itself. Each child can pass by this move it to see what changes and look at the monitor to see the difference in temperature.

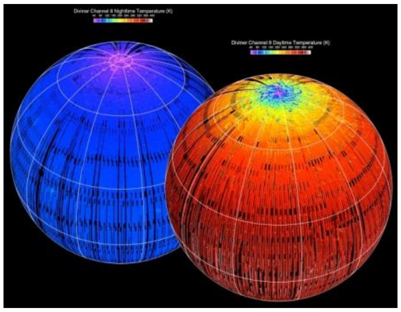
Figure 2.1-33: Lunar Heat Map. NASA

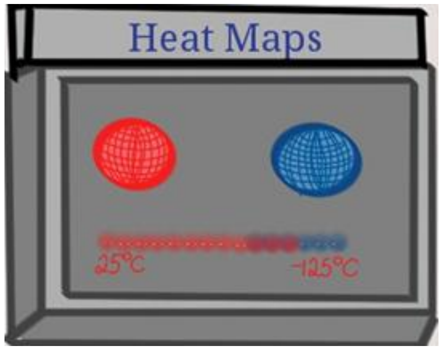

Figure 2.1-34: Lunar Heap Map Thermal Concept

The monitor is an adaptive display that constantly updates heat information received through a camera lens mounted on the rod that orbits the Lunar or Martian globe. The inspiration for the heat mapping is seen on the right depicting the temperature variances on the moon.

This simple design is easy enough for children to read and to understand at a glance without frustrating them or making the relationship between heat and surface unintelligible. The option exists for children attending the exhibit to put their hands in between the light and the globe to block out the light changing the heat on the surface of each of the globes.

Figure 2.1-13 is an image of a Lunar Heat map taken by NASA in 2010.
It depicts the temperature of the surface of the moon depending on the time during its period of rotation where the sun is shining on it. The temperature is indicated to range from -183°C to 117°C.

2.1.9 The NASA Quiz Challenge

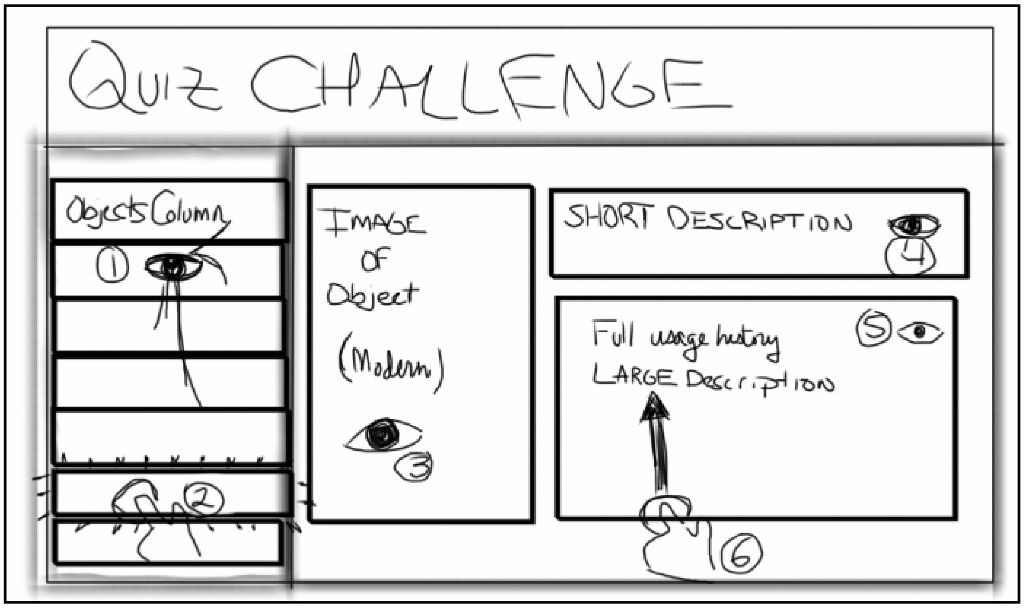

Figure 2.1-35: NASA Invention Quiz Challenge User Interface

This is a highly modular exhibit with multiple entries and catalogs available to be read. Positioned at the edge of a table and angled to be read comfortably, this touch screen display houses a large library of information on the inventions of NASA during the space race. Most of these technologies were "spun off" to make commercial applications of these inventions. The magazine published by NASA, since 1976, named "Spinoff" has been publishing inventions that NASA is responsible and to date they record almost 1,723 such inventions, and those are just the more notable of the variety. Each invention listed on this screen consists of its selection name, a modern image version (alongside a past image of it, maybe), a tagline description of what the invention is and what it accomplishes (1 – 2 Sentences maximum), and a full description as well as history and how the technology works.

The actual Quiz portion is an option on the screen. It changes the layout completely to a multiple choice section for questions relating to either the images of the objects or the short description of the object excluding minute details like the date it was invented.

Objects Columns

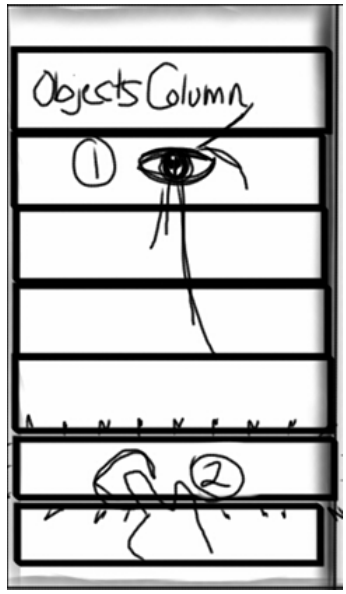

Figure 2.1-36: Objects Column

The Objects Column exists as a list repository of all the items that have been invented by NASA during the era of Space travel to help with the daunting task of making it possible for human survival in zero gravity far-removed from a constant resource. These inventions are also objects that modern technology is based on and are used either somewhat commonly or are integral to society.

Example list[49]:
“Memory Foam”, “The Bionic Ear”, “Scratch-Resistant glasses”, “Water Filters”, “TV Dinners”, “Comfortable Tennis Shoes”, “Power Tools”, “Cell Phone Cameras”, “Sound Imaging – CAT scans and MRI”[50], “The Computer Microchip”, “Ear Thermometer”, “The Game Controller”, “Satellite Television”, “Swimsuits and Speedo”

[49] NASA Spinoff. "About Spinoff." NASA.gov. n.d. http://www.sti.nasa.gov/tto/spinhist.html (accessed 11 2012, 04).

[50] NASA. "At the Hospital with NASA." NASA.gov. July 29, 2004. http://www.nasa.gov/audience/foreducators/postsecondary/features/F_At_the_Hostipal_with_NASA_prt.htm (accessed 30 2012, 03).

Image of Object

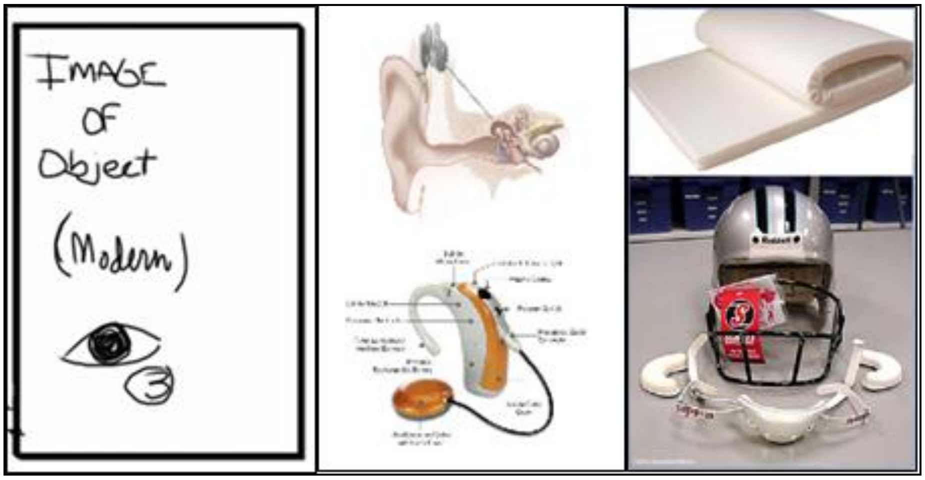

Figure 2.1-37: Image of Object Panel

This section contains the images associated with each item choice. Its implantation allows for the image to be expanded upon touch and reduced in size again when touched. Each image is selected to best exemplify the actual inventions and their modern implementation every child would at least know by first or second degree.

Short Description

Figure 2.1-38: Short Description Panel

The Short Description Block is the tagline of the invention. It contains all the information about the device that is relevant without any details. The name of the invention, when it was invented, and what it is used for are constructed in such a way as to be easily modified and under 3 sentences in length. This brevity is used to give a baseline understanding to any individual who does want to know what the invention itself is. If they are interested in knowing more about the invention, the full usage history and description box underneath contains all that information.

Example Text:

"Memory Foam was invented in 1966 to improve the safety of aircraft cushions. It's used to this day to reduce damage from impact and protect against collisions.[51]"

"The Game Controller, also known as a Joystick, was invented in 1964 to remotely control aircraft. It's used to this day to control electronic video games, remote controlled hobbyist vehicles, airplanes and more."

[51]NASA. Mars Science Laboratory. 2011. http://marsprogram.jpl.nasa.gov/msl/ (accessed 03 10, 2012).

Full Usage History: Large Description

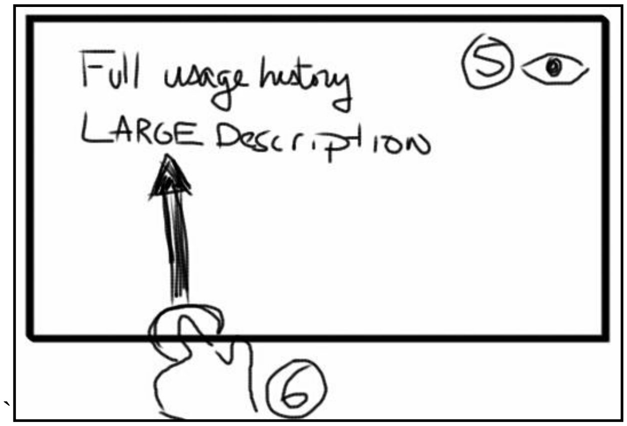

Figure 2.1-39: Full Usage History, Large Description Panel

The Large Description Box contains all the information absent from the Short Description Box. It is a scrollable text box with all the relevant information to the invention's creation and usage throughout history. This information includes the definition of the name, history of its first uses and implementations, and its modern equivalent.

"Memory foam was developed in 1966 under a contract by NASA's Ames Research Center to improve the safety of aircraft cushions. The temperature-sensitive memory foam was initially referred to as "slow spring back foam" or "temper foam". The foam has a structure that matches pressure against it, yet slowly springs back to its original shape.

Memory foam was subsequently used in medical settings. It's been commonly used in cases where the patient is required to lie still in their bed for a long time. The pressure over some of their body regions decreased or stopped the blood flow to the region causing damage to the body. Memory foam mattresses helped with keeping the blood flowing to all parts of the body.

Memory foam was initially too expensive for widespread use but in recent years it has become cheaper. It is most commonly used in mattresses, pillows, and mattress toppers. It has medical uses, such as wheelchair seat cushions, hospital bed pillows and padding for persons suffering long-term pain or postural problems. A memory foam pillow may help with neck pain. It keeps some heat from being on the body which helps some people suffering from pain with the warmth."

2.1.10 *Modeling the Exhibit*

In order to visualize the exhibit we decided to take our 2D concept drawings and bring them into virtual 3D realization using CAD software. We chose to use Solidworks because of its powerful abilities and its accessibility on campus. To begin the design procedure, we established an overall scale for the exhibit. By looking at what we would have available at exhibition shows we set eight-feet-per-section as our main dimension. All other parts were scaled around this. The modeling of the exhibit provided many benefits. Most immediate was the benefit that it allowed us to visualize the physical layout and appearance of our project. The renders also provided us with very nice visuals to use on the website and any other piece of visual communication. However, it wasn't long until we realized that we will be able to use the models to print large portions of the exhibit. This required revisiting all the models to ensure they were to the standards required by the printer. An overview of the materials processing section can be seen in Fig. 2.1-20[52].

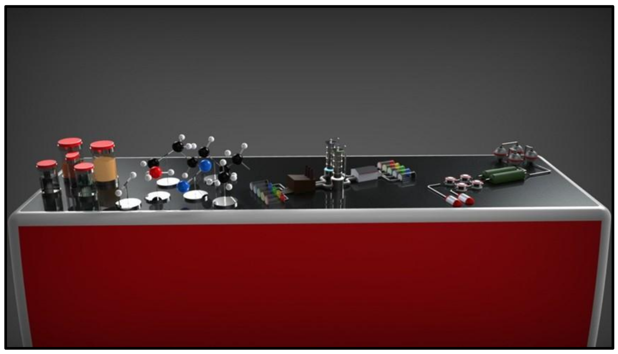

Figure 2.1-40: 3D Render of the materials processing section of the exhibit.

Molecules

The design began with the molecule models. As no team member had extensive experience using CAD software, these simple models provided a good environment in which to learn Solidworks. The beauty of the molecular model parts is that they are derived from common models, so they provide a way for us to streamline and easily expand the molecular information section. The models can even be scaled down as to produce molecular model kits that could be given to or used by students. The models can be seen in Figure 2.1-41[53]

Jars

The next pieces that were modeled were the jars that would contain mock Martian materials to show the raw material from which polymers would be produced. These were a quick part to produce in Solidworks, as it is a simple hollow cylinder with a lid. Additionally, the jars did not have to be actually made because printing in clear polymer is not possible, and it would be simpler to use store-bought jars that could be modified to appear more in-line with the exhibit aesthetics. The jars can be seen in Figure 2.1-42[54].

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[52] Connor W. Ellison, Materials Processing Section 3D Render, CGI Image.
[53] Connor W. Ellison, Molecules 3D Render, CGI Image.
[54] Connor W. Ellison, Jars 3D Render, CGI Image.

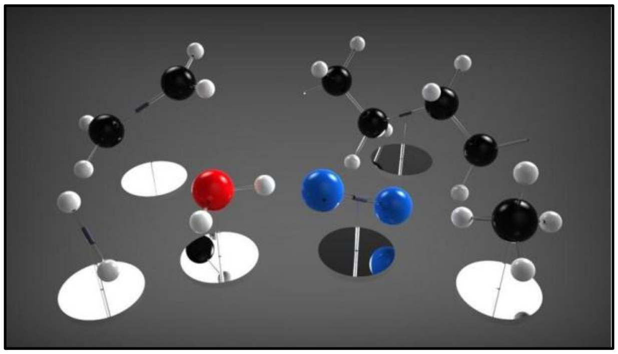

Figure 2.1-41: 3D Render of the molecules portion of the materials section of the exhibit. Counter-Clockwise from lower left: Molecular Hydrogen, Water, Molecular Nitrogen, Methane, Polyethylene, and Ethylene.

Figure 2.1-42: 3D Render of the materials jars.

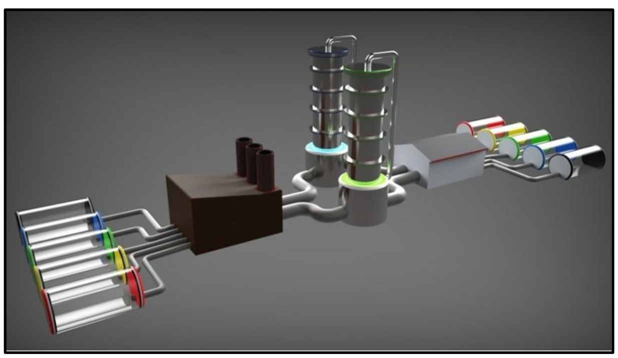

Figure 2.1-43: 3D Render of the earth factory model.

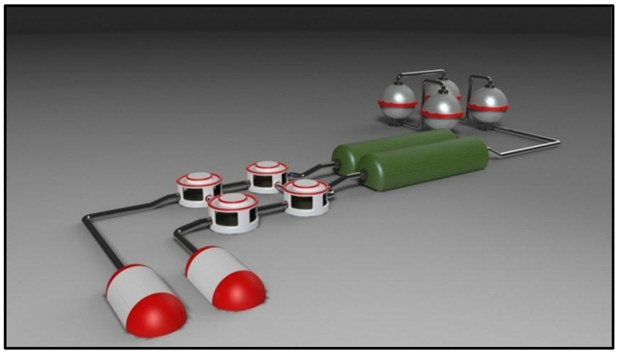

Figure 2.1-44: 3D Render of the Martian factory model.

3.1.7.3 The Earth Factory

The earth factory was a larger scale project, as it consists of eight different unique models, which compose four different assemblies, which compose the overall assembly. Condensing the actual appearance and layout into a simple form that still managed to retain enough information to teach the material was the largest challenge of the earth factory component. This was done by establishing the major steps found in terrestrial factories and representing them with one single building that could be easily explained to audiences. The details of the processes are not what we aimed to teach, but rather the overriding concepts behind the process. The earth factory model consisted of raw material tanks, a factory building for refining raw materials, a reaction section for producing products, a warehouse for processing raw product, and storage tanks for holding finished products. The earth factory model can be seen in Fig. 2.1-22[55].

3.1.7.4 The Martian Factory

We had a lot of freedom with the Martian factory. There is no concrete design plans for a Martian factory, so the aesthetic design was focused more towards making a display that was eye-catching and that the audience would become interested in. The Martian factory is only made of four major assemblies, and is overall simpler in design than the earth factory. We attempted to implement the concept of reusability that would be required during actual polymer processing on Mars. This is the idea that one reactor or piece of equipment can be used in many different processes that lead to different end products. We did this by using multiples of the same part in the overall model design. There are no specific functions assigned to each of the components, but this is part of the way that the idea of adaptability will be shown; one factory setup can be used for multiple different processes. As with the earth factory, the factory has been scaled down and condensed to save on space and to make explaining and teaching concepts simpler. The Martian factory model can be seen in Figure 2.1-43[56].

[55] Connor W. Ellison, Earth Factory Model 3D Render, CGI Image.
[56] Connor W. Ellison, Mars Factory Model 3D Render, CGI Image.

2.1.11 Activity

We created an interactive activity specially geared towards our intended audience to help utilize what they have learned about 3D printers. 6-8th Grade students are given thorough instructions on how to complete the activity. They must rebuild a tool out of Legos where the original tool was broken during the construction of the Mars colony. The activity was presented to the students enrolled in the "Spark!" program hosted by Massachusetts Institute of Technology. These instructions were given to the students:

"Mission on Mars: 3D Print a Part"

Someone has just broken a tool from working and needs your help to build another one. Your mission is to replace the broken tool by printing out a new one. Your group will be provided with Legos for your plastic stock. You are also given a sheet showing the tool you need to create. The tool is shown in different perspectives and is properly dimensioned, allowing your group to correctly print the tool. And remember how a 3D printer works! You have to complete the layer before moving onto the next one.

Once your tool has finished printing, bring it up to the front of the room for inspection. If it doesn't pass inspection, you have to restart the printing process again. The best printers on the market have high accuracy and fast print time. The team that first completes their tool without any errors wins. You have 15 minutes to successfully print the tool, or you will set the astronauts off schedule. Good luck!

The students were paired into groups of 4. Along with these instructions, each group was given instructions on how to build their part. Groups were randomly selected a tool to build. The 3 types of tools were a wrench, monkey wrench, and hammer. They had to build one layer at a time, and the layers were well specified. (See Appendix 6.1 for the activity) As well as instructions, they were also given a sandwich bag of Legos that had more than enough to complete the part.

2.2 Infographics

Infographics are a ubiquitous and essential part of conveying information. These images condense data into a visual format that is easily analyzed and understood by viewers without burdening or overwhelming them with tables full of numbers and other metrics. These documents are large, graphics-centric posters designed to present information that would otherwise be too complex to understand quickly and clearly. A well designed infographic enables the author and presenter of the data to simultaneously turn their data into a work of art and reach a much wider audience than would have been previously possible in the original format. Though the concept is simple, infographics are one of the hardest types of data presentation methods to effectively create.

While the basic concept is straightforward, the design process for infographics is rather involved. On one hand, the visual needs to present good and solid information to the reader, but the method in which you do present it needs to be quick and simple. These two parameters are not often seen simultaneously, but to create an effective and engaging infographic it is necessary that they work in tandem. Have poor graphic presentation of information and the viewer will become either bored or overwhelmed with the data. Conversely, if there is a lack of data, it doesn't matter how well designed the graphic is because it serves no purpose and doesn't convey information. It is a fine line that infographic designers walk, one that needs to be treaded carefully.

Data and images need to work in tandem with an infographic. Concepts need to be quick to grasp and data needs to be easy to digest. This is usually done by having graphics complement data. According to Smashing Magazine, a popular graphic design blog, "When you have an opportunity to display information visually, take it… if a bunch of pictures are missing context, then you are doing too much telling and not enough showing."[57] The graphics of the design should drive the data. The big draw of infographics is that readers will be looking at the pictures and simply skimming over the data; to most people, raw data is uninteresting.

While most people looking at infographics won't be looking to criticize a designer for their sources, it's generally accepted to be a good idea to have reliable sources with authority. Weak sources can discredit a piece of work, and can even sink researchers' careers.[58] Regardless of credibility, bad information will break an infographic - while it may look appealing, that's all it will be.

The best piece of advice for designing an infographic is to simply follow best design practices for websites. Designing an infographic is very similar to designing a website. You need your hook, your design and your content. The graphic design needs to flow nicely, usually from the top of the page to the bottom. Nathan Yau explains this best in one of his graphic design articles. "Remember that design isn't just about making things pretty. It's about making things work, and in the case of infographics, that means representing data accurately and clearly."[59] The data and the images need to work in tandem, playing off each other. Have percentages describing the progress of fuel efficiency? Use a modular bar graph, filling the bars with cars. Does your company have a well-known color scheme? Work it into your design. This is graphic design 101 here and should be fairly straightforward for graphic designers.

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[57] Amy Balliett, "The Do's and Don'ts of Infographic Design," *Smashing Magazine*, October 14, 2011, http://www.smashingmagazine.com/2011/10/14/the-dos-and-donts-of-infographic-design/

[58] Jon Phillips, "4 Key Ingredients for Designing Successful Infographics," *Design Disease*, March 8, 2012, http://designdisease.com/4-key-ingredients-for-designing-successful-infographics/

[59] Nathan Yau, "The Do's and Don'ts of Infographic Design: Revisited," *Smashing Magazine* October 21, 2011, http://www.smashingmagazine.com/2011/10/21/the-do%E2%80%99s-and-don%E2%80%99ts-of-infographic-design-revisited/

While it's very tempting to dive into the design of an infographic, designers need to be very careful. A good design needs to be carefully planned and masterfully executed. While it may seem simple to design one, it isn't. Designers need to be prepared to spend a lot of time playing with various designs before you find one that sticks. The accurate portrayal of data using pictures is also a very difficult task that not many people are able to grasp. A good infographic designer needs to be both proficient in the distillation of information and artistic enough to make an appealing design, a very rare combination.
In our project for the mars foundation, infographics are an ideal medium for conveying information. Their superficially simplistic nature allows younger kids to pick up on the information being conveyed while allowing older viewers to engage on a deeper level with the information. This information can be numerical, such as small factoids about Mars, but if presented in a clean and thoughtful manner, this information has a high chance to stick with children, as it is both appealing to the eye and informative. A small poster with a list of facts displayed is boring, but one that is stylistically advanced and stands out from other visuals can act as a focal point to children, keeping their interest while we pass on knowledge and inspire interest.

"Hey Kids, Why Mars?" Infographic

Figure 2.2-1: Earth Image

Here is the Earth. It's pretty big, it is covered mostly by oceans, and it has been home to a many different types of life, and it has been around for 45 Billion years. Dinosaurs once roamed its surface for hundreds of millions of years almost 245 Million years ago. As far as all of time is concerned, humans have only shown up quite recently and in that time, and we've done a lot in that time. We have gone from living in caves to being the most dominant life form on the planet with civilizations on every continent and the ability to be anywhere in the planet in less than a day's time. We have even accomplished landing on our moon, our closest neighbor, in no time at all. Ours is a race that needs to grow and expand, spiraling outward from our caves to the stars themselves.

Figure 2.2-2: Moon Image

The Moon is our satellite, meaning it orbits us and only us. It has been there since the Earth was cooling. Scientists even say that it may have even crashed into us early in Earth's history remaining in orbit from that point onwards. Its gravitational pull on us allows for the oceans on our surface to create waves and it reflects light from the sun to illuminate the night's sky. For civilizations, humans have used it to navigate the globe during the day or the night, getting to the furthest reaches of the globe because it was there. Once we explored all that there was on the Earth with its help, we pointed our heads to the moon and landed on its surface in 1969. That lunar voyage helped us gain so much more than just the single act of landing and walking on something; we, as a race, rekindled the spirit of exploration and sent our own satellites out to the furthest reaches of space to illuminate what we couldn't see.

Figure 2.2-3: Mars Image

This is Mars. Like the Earth, the moon, and every planet in our solar system, it has been around for Billions of years and NASA scientists believe that, at one point in time, it may have had water and weather similar to what we have on Earth. Mars is now barren, its entire surface is a wasteland, its atmosphere can’t be breathed in, and its water is hidden away under the surface as ice like a precious gem. The truth is that Mars is not a good planet to live on. Or that would be the case if we haven’t come as far as we have with all the technology we have developed.

We use trees to make the air breathable, the sun to power all our devices, and dig for the water to water our crops. We make plastic out of the materials on the surface and build our home away from home.

With a little hard work and ingenuity we can turn this desert into an oasis.

2.3 3D Printers

2.3.1 The Rapid Prototype Printer

Figure 2.3-1: Dimension® 1200es series

To build the processing factories for the exhibit, the components were printed on a Rapid Prototype printer located in Higgins Labs on campus. The printer is a Dimension® 1200es series (see Figure 2.3-1), and is more industrial than the MakerBot printer. It has a build area of 10" x 10" x 15" and has a dimensional accuracy of +/- 0.006 inches. In other words, parts made on this printer have a higher resolution and its shape is more defined. This printer is open to students who wish to use it, and can print out almost any part if it follows certain criteria. It must be properly dimensioned, where its dimensions are within the build area. Files must be sent via ZIP file with a fee of $4 per cubic inch. This printer can print in different colors, so parts should be specified what color it needs to be printed. We decided to print it in white, and then used paint that works on ABS plastic to add details. We created each processing building in CAD using SolidWorks. After double checking the dimensions to make sure it was printable and within build area, the parts were sent in a zip file to an administrator in charge of the rapid prototype printer. The CAD files were then sent to the printer to extrude the parts. Once the printing process was complete, the parts were put into a tank filled with a solution for several hours to dissolve any support that could not be removed.

We were able to print out a small Yoda head in order to compare the resolution of the Rapid Prototype printer to the Makerbot. The total came to $15.56 and it was printed with white plastic. After examining the Yoda head, we saw that the resolution was better on the Rapid Prototype than the Makerbot printer. Cost does make a difference in the quality of the product.

2.3.2 MakerBot

Fixing the 3D Printer

On February 11th of 2012, we acquired a non-functional 3D printer from the robotics department. Repairs were attempted on the 3D printer to get into a functional state that would likely print a part inside of three weeks. First up, was connecting the different circuit boards together to make them communicate. Several 10pin ribbon cables had to be carefully modified into 6pin ribbon cables so as to match pin connections with each board. When all the parts were connected, the only thing left to do was attempt to run it. Nothing happened when we initially ran the system, the parts were connected but there wasn't a response. We tried another motherboard, this one accommodating the newest stepper motor drivers that were required to run the platform and the extruder pinch wheel. At first there was relief that the platform was capable of functionally moving in the x, y, and z directions without issue, however, we came across the issue that the extruder controller was not receiving any signal from the motherboard it could interpret and was, as a result, not delivering any feedback to run the extruder head off of.

We returned to the older motherboard with different firmware and newer connectors as well as soldered wire jumping across boards and we were able to get the entire system to operate. Upon completion of this setup, troubleshooting brought us to a defective thermistor on the Extruder Controller that needed replacing. After the thermistor was replaced, the extruder could easily produce high enough temperatures to melt the plastic stock, but the actual printing itself was not possible because the stepper motor driver for the extruder was unresponsive.

Components:

- Stepper Motor Driver (v2.4) – 3
  - Drives the print platform in the X, Y, and Z directions
- Extruder Controller v3.6
  - Drives the pinch wheel for the Extruder feed as well as sends a control signal to Relay Switch
- Relay Switch
  - Turns the heating element on and off for the Extruder head.
- Motherboard Shield for Arduino Mega 2650
  - Adapts the Arduino Mega to communicate to different boards on the 3D printer
- Arduino Mega 2650
  - Microcontroller capable of 16MHz frequency
  - Atmega2560 – 8-bit AVR CPU[60]
- Motherboard v1.2[61]

[60] ATMEL. ATMEGA2560. n.d. http://www.atmel.com/devices/atmega2560.aspx (accessed Feb 2012).

- Previous version of the Motherboard for the MakerBot platform
    - Capable of 20MHz frequency
    - Atmega644p – 8-bit AVR CPU[62]
- MakerBot Assembly Structure
    - Purchased structural assembly from MakerBot.
    - Houses Electronics. Figure 2.3-2: MakerBot CupCake Electronics Configuration with Arduino AtMega2650

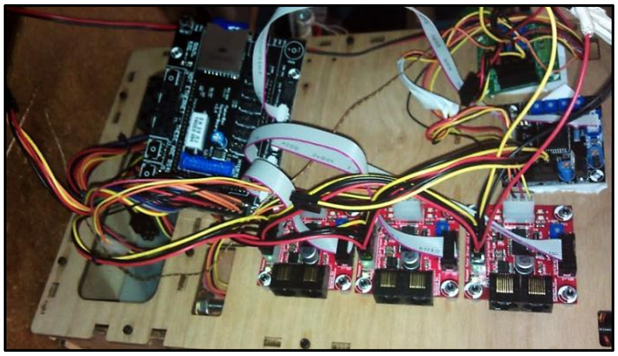

Figure 2.3-2: MakerBot CupCake Electronics Configuration with Arduino AtMega2650

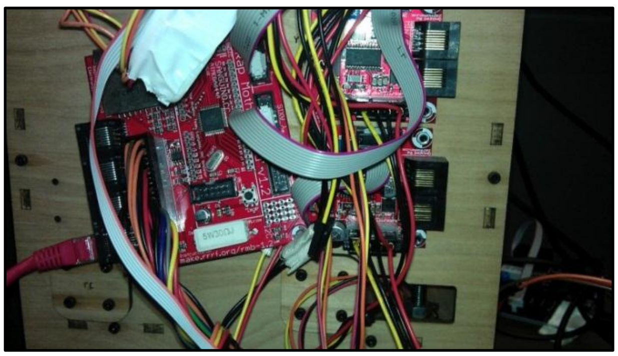

Figure 2.3-3: MakerBot Cupcake Electronics Configuration with Motherboard 1.1

2.4 Public Appearances

2.4.1 Spark! at MIT

Every year, hundreds of 7-12th Grade students travel to Massachusetts Institute of Technology to take several, one-hour classes. Our team was invited by our sponsor to present the MakerBot printer and to test the interactive activity. There were two, one-hour time slots the students could choose from: one at 10am and one at noon. Upon selection time for the students, the 3D printer class created much interest. In respect to the time slots available, 35 and 22 students put it as their first choice. The classroom only holds 16 students per time slot, so those students had to go through a lottery to see if they

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[61] RepRap.org. MotherBoard 1.1. 2009. http://reprap.org/wiki/Motherboard_1_1 (accessed Feb 2012).

[62] AtMega644p. 2009. http://www.atmel.com/devices/atmega644p.aspx (accessed Feb 2012).

got admitted into the class. 89 and 71 students put the project as their first or alternate choice. The majority of students were home schooled or go to private school. The students were mostly 7th and 8th graders, but there were a few 9th graders interested.
The day set for Spark! this year was March 10th. There were 16 students in the first class, and only 7 in the second class. When entering the classroom, the students noticed the 3D printer easily while it was on and moving. Before sitting down, they got to examine the printer up close. Because of a faulty extruder controller, the printer could not actually print anything. Other than that it could move in all directions. The students were still fascinated by the turning motors and flashing lights. The activity was presented during the final 15 minutes of the time period. It took 5 minutes maximum for the groups to complete the activity, which was understandable since it was made in mind for public school students. The students said that it was too easy and wanted to be challenged more. They also said that the layering instructions were not clear enough.

2.4.2 SEE Science Center

The SEE Science Center is an interactive learning center established to promote the understanding, enjoyment and achievements of science, mathematics and technology. The SEE Science Center was dedicated in April of 1986 and has since been engaging visitors of all ages in the pursuit of science discovery. SEE is a member of the Association of Science and Technology Centers and their passport program. The SEE Science Center's sole branch in Manchester, NH is open 7 days a week [63]**.** SEE is an IRS designated 501(c)3 non-profit organization, voted by Hippo readers in the 2011 Best of Reader's poll overall winner "Best Place to Take Your Kids" 5 years in a row and overall winner as "the best place to take your kids on a rainy/snowy day" 4 years in a row.

On April 21st of 2012, the Mars Settlement and Fabrication Exhibit Design Project team visited the SEE Science Center to discuss and promote the Mars Settlement and Fabrication exhibit design to Mr. Douglas Heuser, the center's director. The project team was given the liberty to see the center's exhibits in their entirety and make note of the designs and features that went into them. The meeting with Mr. Heuser allowed for the project team to present the concepts and designs for a full plan exhibit that would be incorporated into the Center's floor plan as a permanent exhibit. Most of the feedback on each individual component was positive.

[63] SEE Science Center. About Us. n.d. http://www.see-sciencecenter.org/about-us/default.aspx (accessed 04 25, 2012).

2.4.3 *AIAA Space Conference & Exposition*

The Mars Settlement and Fabrication Exhibit Design team applied for a conference and expo sponsored by the American Institute of Aeronautics and Astronautics held in Pasadena, California on September 11-13. An abstract of the project was submitted in order to be considered for the conference. Responses on acceptance to the conference are sent out in April. If accepted, one of our teammates will present our project in front of distinguished members of the AIAA, provided if the student can afford to go.
We received an email confirming our admittance to the conference. However, the group remains undecided in whether we should attend. As of now, we do not have the money to fund one of our teammates to present in Pasadena. The conference is also in the middle of next *A*-term which conflicts with our academic schedule.

3. Recommendations

3.1 Education

3.1.1 *The Massachusetts STEM Curriculum In Middle School*

In order to accurately prepare a school presentation for Middle School children, project teams need to understand what exactly students have learned, and are expected to know at the time, while also being relevant to the current topics teachers are trying to reinforce. Thankfully, the Massachusetts Department of Education regularly publishes this information as it is updated, and keeps it open for outsiders to look at. It is suggested that when planning a presentation, one check to see that these are accurate and have not been changed. As of March 2012, the documents specifically noting Science and Technology education were last updated in October of 2006.

The Massachusetts Science and Technology/Engineering Curriculum Framework was a boon for planning the presentation. It gave us a good look as to where the children were in their studies, and allowed us to plan around what topics teachers were giving the students, as well as what prior topics that they have gone over. This gave us the information needed to be able to plan accordingly and provide a tailored presentation for that age group, though care must be used if giving a presentation to a class in private school, as they won't necessarily follow the Department of Education's suggested curriculum.

3.1.2 *Reaching out to Schools*

One of the issues we ran into when trying to get in contact with schools is the amount of lead time needed in order to be slotted into the classroom. Out of respect for both the teachers and administrators, project teams should reach out to schools well in advance to a presentation date in order to make it easier to get a presentation time. They should also be well prepared to share what exactly the presentation consists of, so that the school knows exactly what will be going on. This will help smooth the process over and make it easier for everyone involved, increasing the chances of getting a presentation slot.

With private schools, it is generally much easier to get a presentation slot, as to the leniency of programs, and less state red tape to muddle through, but care still needs to be taken as they generally do not follow the state education curriculums. Extra time should be taken, especially in case the presentation needs to be altered in order to stay relevant to the class. Though the chances of having the presentation be altered is higher with a private school, its generally advantageous to target such institutions, as project teams would have a much better time getting presentation slots there, rather than in public schools.

3.1.3 School Visits

Before we even put our exhibit in a museum, we wanted to test it to our selected audience. We contacted schools within the Worcester area and Greater Lowell area through formal letter and email to see if they would be interested in having us present at their school. Unfortunately, Worcester Public Schools could not accommodate us into their school's strict curriculum. We also heard no reply from St. Louis School in Lowell about their interest in our project.

We recommend for the continuing group to contact schools as soon as possible. It is hard for teachers to adjust their syllabus for their classes. They are required to teach the list of topics to their students by the end of the school year. For public schools, teachers have to prepare the students for the MCAS exams and cannot afford to waste learning time in the classroom. However, we believe that connections with schools can be established if given enough notice. Thus A term would be the best time to contact schools.

3.2 The Activity

We created a fun, interactive activity to help the visitors utilize what they have learned through the exhibit. In this activity, visitors must "print" a tool using Legos as their plastic stock. The original tool broke during construction on the Mars base. They are given dimensions of the tool and must assemble the Legos correctly. They must print layer by layer. The first prototype of the activity was presented to the students at Spark! The level of difficulty was too easy for the students. Students were given what Lego pieces to use to construct the tool. They recommended showing the shape of the tool and giving how many layers to print instead. However, they did enjoy playing with the Legos. We recommend fixing the difficulty level to coincide with their grade level, making the activity more fun to do. We also encourage the next group to come up with alternative activities that can teach and engage the students.

3.3 Funding

The construction of an exhibit is an undertaking that will require funding in order to bring our design concept from a written design to a full-fledged physical medium. While creating a thorough and complete exhibit design on paper is a low-cost endeavor, the financial backing required to build a well-maintained traveling exhibit is an undertaking that will require financial backing. The cost of museum exhibits has a wide range; it can cost as little as $75.00 or as much as $650.00 per square foot. For an interactive science museum exhibit, the up-front cost of construction is on the higher end, between \$550.00 and \$600.00.[64] This figure excludes consultation, design, maintenance, advertising, or personnel costs. Fortunately, the cost of de- signing a smaller single-display exhibit can be assessed on a per-component basis, and funding can be allotted in advance that cover the costs involved with running the exhibit, transporting it to new locations, general maintenance, and the setup and breakdown costs. Our sources of funding consist of federal and private grants, donations from corporations, private "angel" donors, and funding obtained from multiple sources granted to us via the Mars Foundation.

3.3.1 Government Grants

Funding from the government sector is the most available and accessible type of funding that we can seek out and procure. With large organizations dedicated to the advancement of education in science, technology, engineering, and math (STEM) fields, we have a span of resources potentially at our disposal. The main concern with government funding is the understanding of nuances of each grant's criteria of eligibility and their associated due dates; precision and timeliness are key when dealing with government funding, especially because multiple groups are competing for grants and money. Additionally, there is such a wide range of funding opportunities afforded by the government and its organizations, we face the challenge of distilling and concatenating the available options down to a select few of which we fit the criteria and are within the range of eligible application dates. While the government has a plethora of organizations that provide funding for education and STEM fields, our type of project eliminates a large portion of them because we are designing a museum exhibit, not a classroom or scholastic program. After investigating the range of federal funding opportunities, we evaluated that our two best options to focus on would be the National Science Foundation (NSF) and the Institute of Museum and Library Services (IMLS).

[64] Jay Rounds and Joyce Cheney, Formalizing Exhibit Development, Exhibitionist 21, no. 1 (2002).

3.4 National Science Foundation (NSF)

The National Science Foundation provides the widest range of funding opportunities. This is both advantageous and detrimental to our efforts. The problem with having such a wide range of grants to choose from means that we need to be very precise in our approach to selecting one; if we aren't careful, we could end up wasting effort on a proposal for a grant we weren't eligible for in the first place. The other major challenge is competition. The NSF receives over 40,000 proposals every year. Approximately 11,000 of these are accepted and receive funding.[65] By applying for grants at the NSF we put ourselves in a very large pool of applicants. Conversely, we have the advantage of having a very unique goal and funding requirement. The scope of NSF funding is usually for research, science, and educational endeavors. Our museum exhibit falls on the fringes of their grant opportunities, but this will limit the number of grants for which we are eligible and will act as a self-selecting mechanism. Overall, the NSF presents huge potential for funding the design of the exhibit, but must be approached carefully and evaluated thoroughly before selecting it as a source of funding.

3.4.1 Institute of Museum and Library Services (IMLS)

The Institute of Museum and Library Services presents a much more narrowly focused funding program, with its grants targeted specifically towards museums and libraries and programs that are geared towards growing and improving them. This gives us the advantage of having a tightly focused audience. Unlike the grants that the NSF provides, we would not have to search through hundreds of unrelated funding opportunities to find the select few that we could apply for. The downside to searching for funding through the IMLS is that their funding is primarily focused towards existing institutions and organizations. As an independent group that is designing a museum exhibit, we fall into a grey area of eligibility because we do not meet every last criterion for eligibility. In this situation, they state that "[p]rospective applicants that cannot fulfill all of [our] requirements should contact IMLS to discuss their eligibility before applying".[66] If we were to approach them as a third party that is building an educational exhibit for travel to multiple points of display, we may be able to present the case that the wide range of benefit and is enough in-line with the goals of the organization that it warrants their funding. The other major option would be to procure funding through a museum as a project organizer. The obvious choice for us would be through the Boston Museum of Science (BMOS); since the BMOS is a non-profit museum, this would be a viable option pending contact and the cultivation of a partnership with the museum.

[65] National Science Foundation, *About Funding*, http://www.nsf.gov/funding/aboutfunding.jsp.

[66] Institute of Museums and Library Services, *Eligibility Criteria: Museums*, http://www.imls.gov/applicants/museums.aspx.

3.4.2 *Corporate Grants and Donations*

The highest potential sources of funding are found in the corporate sec- tor. There are countless corporations and companies that actively sup- port educational programs, especially those that promote growth in STEM fields. Companies supporting STEM education range from small businesses up through technology giants such as Google, Intel, and Microsoft. These corporations give billions in support of programs that give students the opportunity to gain exposure to STEM and succeed in its curriculum. The large support that today's innovators provide to advancing education in the most promising and pivotal fields indicates that they are prime targets for us to approach for funding and support. Additionally, we can approach companies that are major players in industries directly related to subject matter pertinent to the topic of the exhibit. Companies like SpaceX and ZCorporation are involved in the development, manufacture, and sale of products that would be integral to the exploration and settlement of mars. Looking at the corporate sector, we can clearly see that we have numerous opportunities to pursue funding from sources that are both related directly to the topic of our project and that have a record of funding programs that advance STEM education.

3.4.3 *Private Investment*

A third option for funding the exhibit is through private investors. Through networking and outreach, we may be able to contact parties that would be interested in funding the development, construction, and implementation of our proposed mars settlement exhibit.

3.4.4 *Procuring Funding*

In order to acquire the support of any federal grant, corporation, or individual donor, we are creating proposals that demonstrate the goals of this project, detail the expenditure of funds, and justify the use of funding for the design and construction of the exhibit. We are currently writing proposals to the Mars Foundation to tap their coffers for a small sum to purchase the smaller 3D printer that will allow us to begin prototyping the exhibit. Writing proposals requires that we analyze our goals and our funding audience, compose the content of the proposal, and then follow-up and evaluate what we have written to ensure it meets all necessary requirements and speaks to our intended audience. The Analyze-Compose-Evaluate (ACE) process, presented by Shwom and Gueldenzoph in *Business Communication*, has given us a set of tools and a procedure with which are able to better understand our audiences for finding and obtaining funding, which helps us tailor proposals specific to each individual potential donor, thus increasing our chances of receiving funding and/or support.[67] We are submitting proposals for money to the Mars Foundation before the close of the tax year in order to capitalize on a prime period for procuring funding. Throughout the course of the project, we will constantly work to identify, evaluate, and pursue other sources of funding the exhibit.

[67] Barbara Shwom and Lisa Gueldenzoph Snyder, *Business Communication: Polishing Your Professional Presence* (New Jersey: Pearson Education Inc., 2012), 252-260.

3.5 Website

The development of our website, marsexhibit.org, was an endeavor that resulted in failure but had and still does have a significant amount of potential. Originally, the website was to serve as an internal communications device and a planning service so we could communicate between each other and have all documents and timelines held in a central place. We attempted to implement project management software called dotProject in an effort to set goals and maintain a more organized schedule, but it was not easy software to use and it resulted in many hours of frustration for the people using it and even more hours of frustration for the team member who was managing it. When it was apparent that the use of management software was going to waste more time than it saved, we abandoned that idea and decided to make the website focused on external support and using it as a fundraising tool.

Before any of this could happen, we ran into problems with the content management system. Initially designed on WordPress, we found out far too late about its limitations for building the type of website we wanted. We switched content management systems to a platform called Concrete5 in an effort to solve this, and for a short while things were working: the website was running smoothly, it looked nice, it was easy to edit and work with, and we finally felt that we had something presentable for the public.
Except for content.

Content was and still is the hardest part of maintaining such a website. Everyone on the team needed to be comfortable and able to write regular blog posts about the sections of the project on which they had worked. This didn’t happen, however, and the blog floundered and slowly died after two weeks. It was never anything we could have or did show a sponsor, and the writing on there would have only hurt us rather than help us.

When approaching this idea, we didn’t account for the overhead of time and effort for maintaining the website. If you choose to utilize a personal website to garner funding for your project, ensure that every team member is comfortable and able to write blog posts about their work. Without a steady flow of content people will lose interest and faith in your project.

3.5.1 Blog Posts

During the second term of this IQP, it was decided that in order to generate interest in the project, the group would design a blog. The expected outcome would essentially be hitting two birds with one stone; buzz would be generated for the project, and content could be created that would eventually be used in the final report. Work started out okay at the beginning. The team would update it with a blog post weekly, whether it was an update on the project’s progress, or some basic information pertaining to the current trajectory the team was going in. Unfortunately, the blog did not take off, and eventually became a source of frustration for the team. The team quickly ran out of topics to discuss and due to technical issues with the 3D printer, ended up only generating fluff content, nothing that could really be used in the report, and nothing particularly interesting for those interested in the project. It was a veritable flop.

The team was unable to effectively market the blog to anyone due to a lack of content, quality and a shifting website design, resulting in a blog that would simply not be read due to lack of interest. These issues are rather simple in nature and with proper planning, something that the team really didn't have when it came to the blog, could have been easily avoided. Many of the issues that the team faced, specifically when attempting to market the blog, were due to this poor planning, and had it been handled better, the blog would have actually been worthwhile.

The plan would have had to include a well thought out design that should be kept to, and not changed in the middle of the project's lifecycle, what types of articles to be posted and when, as well as a few backup pieces to post on the website, in the case that teams encounter a week where not much was achieved that could be posted to the blog. The biggest piece of the plan that teams would need, would be for the advertising. This is one of the most crucial aspects of a successful blog. Teams could have the most well-written and relevant content in the world, but if nobody knows your blog exists, who will see it? Advertisements could include anything such as link backs, mailing lists, even word of mouth. With the prevalence of social media nowadays, and websites such as Facebook and Reddit, there is no reason why the blog isn't out there. There is always an audience for your project, teams just need to look for them, and plan in advance.

The most irksome difficulty the team faced was the fact that halfway through the project's lifecycle, the code platform on which the blog was hosted was changed. This is a design nightmare, especially for those who get used to a system. Not only is this confusing to the blog's readers, as the design also changed, but it's frustrating for those writing content. When teams are planning on what they will use to run the blog, they need to pick a code platform and stick with it. Every week, there is another code platform for blogging released, and if teams are always running for the cutting edge, they will lose focus, and eventually run out of steam. Many large companies who are well respected have gone defunct in this way, and most companies would flat out fire developers if they were to try and switch platforms in the middle of a project.

Blogs are a great way to drum up interest for any number of topics; the hard part is executing them effectively. Blog writers need to know what exactly their goal is. Is your blog silly or serious? Does it focus on the technical aspects of your topic, or the final product? What is your blog's audience? Does it appeal to this audience? All of these questions are important to ask before teams launch their blogs. It will help keep teams focused and on the right path. And the most important advice for teams is for them to pick a plan and stick to it.

4. **Conclusion**

Over the course of this project, the Mars Exhibit Design IQP has drafted the components for a full scale mars-focused exhibit geared towards middle school children in grades 5 through 8. The physical exhibit is to be built, owned, and operated by The Mars Foundation. We have detailed the background research and information that we utilized throughout our design process, how and why we designed each section, how the exhibit is to be implemented, and a visual representation of each part of the exhibit. The entire design is modular, allowing the exhibit to be scaled both up and down depending of the needs of The Mars Foundation. This allows the exhibit to be applicable in many situations, whether it is a full scale exhibit in a museum, or a short classroom presentation. The Mars Exhibit Design IQP has provided the Mars Foundation, our sponsor, with content for public interest on their website www.marsfoundation.org, a design package to be turned over to professional exhibit designers who will work with The Mars Foundation to construct the exhibit, and a proposal for the Mars Foundation to use with potential sponsors for the exhibit.

5. Bibliography

"3D Systems Debuts First Consumer 3D Printer." 3D Systems. January 9, 2012. Accessed February 2, 2012. http://www.3dsystems.com/press-releases/3d-systems-debuts-first-consumer-3d-printer.

"About Spinoff." NASA Spinoff. Accessed April 11, 2012. http://www.sti.nasa.gov/tto/spinhist.html.

"About Us." SEE Science Center. Accessed April 25, 2012. http://www.see-sciencecenter.org/about-us/default.aspx.

"Apollo 11." The History Place. 1999. Accessed March 20, 2012. http://www.historyplace.com/unitedstates/apollo11/index.html.

Balliett, Amy. "The Do's and Don'ts of Infographic Design." Smashing Magazine. October 14, 2011. Accessed April 14, 2012. http://www.smashingmagazine.com/2011/10/14/the-dos-and-donts-of-infographic-design/.

Barrett, Anita. "NASA Spinodds Extend Life on Earth." NASA.gov. March 31, 2006. Accessed March 30, 2012. http://www.nasa.gov/vision/earth/technologies/human_spaceflight.html.

Beasley, Dolores. "NASA Advances Water Recycling for Space Travel and Earth Use." NASA News. 03 12, 2004. Accessed March 31, 2012. http://www.nasa.gov/home/hqnews/2004/nov/HQ_04372_water_recycling.html.

Bilton, Nick. "Makerbot Introduces Larger, Two-Color 3-D Printer," Gadgetwise - The New York Times. January 10, 2012. http://gadgetwise.blogs.nytimes.com/2012/01/10/makerbot-introduces-new-larger-two-color-3-d-printer.

Bitgood, Steve and Don Patterson. "Principles of Exhibit Design." Visitor Behavior 2, no. 1 (1987): 4-6.

Centre for Educational Innovation & Technology. Yoda Bust Print of PLA Plastic. Photo. n.d. http://ceit.uq.edu.au/system/files/news/yoda.jpg.

"Cochlear Implants." National Insitute on Deafness and Other Communication Disorders. March 2011. Accessed March 13, 2012. http://www.nidcd.nih.gov/health/hearing/pages/coch.

Crossman, Frank and Milligan, Robert .Aliphatic Organic Synthesis Sequence. Image.

Crossman, Frank. "Building a Self-Sustaining Permanent Settlement on Mars." 4Frontiers. August 8. 2012. http://www.marsfoundation.org/files/IQP-Mars/Crossman_Juniper_8_12_07c.pdf.

Crossman, Frank. Inner Solar System Trade. Image. Building a Self-Sustaining Permanent Settlement on Mars Presentation.

Crowley, Kevin, Takeshi Okada, and Christian D. Schunn. Designing for Science.

Dave Durant’s Blog. “60% Scale Yoda Bust Print.” Photo. n.d. http://i.imgur.com/rmZGK.jpg.

Davis, Jennifer. "Peoria's first cochlear implant surgery has Peroria granfather rediscovering life." Pjstar.com. October 29, 2009. Accessed November 4, 2012. http://www.pjstar.com/features/x876590686/Peoria-s-first-cochlear-implant-surgery-has-grandfather-rediscovering-life.

Driscoll, David P. “Massachusetts Science and Technology/Engineering Curriculum Framework.” Massachusetts Department of Education. 2006.

“Evolution: New Category.” The Pirate Bay. January 23, 2012. Accessed March 26, 2012. http://thepiratebay.se/blog/203.

“Facing Mars." Ontario Science Centre. Accessed November 17, 2011. http://www.ontariosciencecentre.ca/facingmars/.

Fishel, Catharine. Designing for Children. Gloucester, MA: Rockport Publishers, 2001.

“Forty-Year-Old Foam Springs Back With New Benefits." NASA. 2005. Accessed April 4, 2012. http://www.sti.nasa.gov/tto/Spinoff2005/ch_6.html.

Glover, Ken, and Eric M Jones. “Apollo Lunar Surface Journal.” NASA. Accessed October 2011. http://www.hq.nasa.gov/alsj/.

Hamilton, Calvin J. "Chronology of Space Exploration." Views of the Solar System. June 18, 2009. Accessed March 20, 2012. http://www.solarviews.com/eng/craft1.htm.

Hanna, Peter. “The next Napster? Copyright questions as 3D printing comes of age.” ars technica. April 2011. http://arstechnica.com/tech-policy/news/2011/04/the-next-napster-copyright-questions-as-3d-printing-comes-of-age.ars/1.

Hmelo-Silver, Cindy E, Ravit Golan Duncan, and Clark A Chinn. Scaffolding and Achievement in Problem-Based and Inquiry Learning: A Response to Kirschner, Sweller, and Clark. Lawrence Erlbaum Associates, Inc., 2006.

HubbleSite. 03 01, 2012. http://hubblesite.org/ (accessed 03 20, 2012).

“Inducted Technology: Anti: Corrosion Coatings." NASA. 2011. Accessed April 11, 2012. http://www.nasa.gov/50th/50th_magazine/scientists.html.

“Inducted Technology: Cochlear Implants." Tecchnology Hall of Fame. 2011. Accessed April 11, 2012. http://www.spacetechhalloffame.org/inductees_03_Cochlear_Implant.html.

“Inducted Technology: Scratch-Resistant Lenses." Space Technology Hall of Fame. 2011. Accessed April 11, 2012. http://www.spacetechhalloffame.org/inductees_1989_Scratch_Resistant_Lenses.html Fame. 2011.

“Insulin Delivery System." NASA. May 1, 2011. Accessed March 20, 2012. http://www.sti.nasa.gov/spinoff/spinitem?title=Insulin+Delivery+System.

Johnson, S.W. and R.S. Leonars. Evolution of Concepts for Lunar Bases. Houston, TX: Lunar and Planetary Institute, 1985.

Kiger, Patrick, and Marianne English. "Top 10 NASA Inventions." How Stuff Works. 2012. Accessed March 31, 2012. http://science.howstuffworks.com/innovation/inventions/top-5-nasa-inventions10.htm.

Kirschner, Paul A, John Sweller, and Richard E Clark. Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching. Lawrence Erlbaum Associates, Inc., 2006.

Lockney, Daniel. "Featured Invention: NASA Spinoff Technology Helps Detect Cardiovascular Disease." Spinoff Magazine. 2007. Accessed March 31, 2012. http://askmagazine.nasa.gov/issues/31/31s_featured_invention.html.

Lunar Prospector. October 2, 2001. http://lunar.arc.nasa.gov/index.html (accessed 03 27, 2012).

Mackenzie, Bruce A.."Homesteading Mars." In Engineering, Construction and Operations in Space, edited by Stewart W. Johnson, 465-479. New York: ASCE, 1988.

Mackenzie, Bruce. "Building Mars Habitats Using Local Materials." Case For Mars III. AAS, n.d.

Mahwah, NJ: Lawrence Erlbaum Associates, Inc., 2001.

MakerBot Industries, Fully assembled MakerBot Replicator, n.d., photograph, http://store.makerbot.com/media/catalog/product/cache/1/image/9df78eab33525d08d6e5fb8d27136e95/t/h/thereplicator

Marconi, Elaine M. "Water, Water, Everywhere!" NASA.gov. May 13, 2004. Accessed March 30, 2012. http://www.nasa.gov/missions/science/f_water.html.

Mars Homestead Project - Gas Plant." The Mars Foundation. 2006. Accessed April 30, 2012. http://www.marshome.org/files2/MarsHomestead-GasPlant.ppt.

Mars Science Laboratory. 2011. http://marsprogram.jpl.nasa.gov/msl/ (accessed 03 10, 2012).

Matson, John. "NASA's moon orbiter returns promising early data in the hunt for lunar water ice." Scientific American, September 17, 2009. http://www.scientificamerican.com/blog/post.cfm?id=nasas-moon-orbiter-returns-promisin-2009-09-17.

"MHP Manufacturing Systems Concept Presentation." The Mars Foundation. 2005. Accessed April 30, 2012. http://www.marshome.org/files2/MarsHomestead-Manufacturing.ppt.

"MotherBoard 1.1." Reprap.org. 2009. Accessed February, 2012. http://reprap.org/wiki/Motherboard_1_1.

"NASA Technology Helps Detect and Treat Heart Disease and Strokes." NASA. June 6, 2007. Accessed April 11, 2012. http://www.nasa.gov/vision/earth/technologies/artery-20070606.html.

NASA. "At the Hospital with NASA." NASA.gov. July 29, 2004. http://www.nasa.gov/audience/foreducators/postsecondary/features/F_At_the_Hostipal_with_NASA_prt.htm (accessed 30 2012, 03).

New York Times. MakerBot Thing-O-Matic Infographic. photograph. September 15, 2011. http://graphics8.nytimes.com/images/2011/09/15/technology/15basics-web/15basics- web-jumbo-v2.png.

O'Connell, Frank. "A Machine That Gives Shape to Your Ideas." The New York Times (New York, NY). September 14, 2011.

Peakarik, Andrew. "Developing Interactive Exhibits at the Smithsonian." Report, Smithsonian Institution, 2002.

Petrov, G., B. Mackenzie, M. Homnick, and J. and Palaia. "A Permanent Settlement on Mars: The Architecture of the Mars Homestead Project." Technical Paper, SAE Technical Paper, November 7, 2011.

Phillips, Dr. Tony. "Approaching Mars." NASA . 2003. Accessed March 18, 2012. http://www.nasa.gov/vision/universe/watchtheskies/18jun_approachingmars.html .

Phillips, Dr. Tony. "Super Full Moon." Science@NASA. March 16, 2011.Accessed March 20, 2012. http://science.nasa.gov/science-news/science-at-nasa/2011/16mar_supermoon/.

Phillips, Jon. "4 Key Ingredients For Designing Successful Infographics." March 8, 2012. Accessed April 14, 2012. http://designdisease.com/4-key-ingredients-for-designing-successful-infographics/.

Planco, James. "Making Mars Relevant." Spacewatch, 1992. via http://www.astrodigital.org/mars/whymars.html.

"Plastics." The Mars Society Winnipeg. 2010. Accessed March 18, 2012. http://chapters.marssociety.org/winnipeg/plastics.html.

Rayl, A. J. S. "NASA Engineers and Scientists- Transforming Dreams into Reality." NASA. 2008. Accessed April 11, 2012. http://www.nasa.gov/50th/50th_magazine/scientists.html.

"Rescue Equipment." NASA. 1995.Accessed March 30, 2012. http://www.sti.nasa.gov/tto/Spinoff2010/pdf/Spinoff2010.pdf.

Ryan, Johnny. "Manufacturing 2.0: The rise of 3-D printers." CNN Money. May 23, 2011. http://tech.fortune.cnn.com/2011/05/23/manufacturing-2-0-the-rise-of-3- d-printers/#more-60036.

Ryzik, Melena. "3-D Art for All: Ready to Print." The New York Times (New York, NY). May 13, 2011.

Salisbury, Frank B. "Lunar Farming: Acheiving Maximum Yield for the Exploration of Space." American Society for Horticultural Science, 26, no. 7 (1991).

“Spinoff: Frequently Asked Questions." NASA. April 11, 2012. http://www.sti.nasa.gov/tto/spinfaq.htm.

“Tegra 2 Specifications." NVIDIA Corporation. January 7, 2012. Accessed March 20, 2012. http://www.nvidia.com/object/tegra-superchip.html.

“The Economic Viability of Mars Colonization." The Mars Society. 1999. Accessed March 20, 2012. http://www.marspapers.org/papers/Zubrin_1995.pdf .

The Mars Foundation. "Mars Homestead Polymers Powerpoint Presentation." Marshome.org. 2005. Accessed April 30, 2012. http://www.marshome.org/files2/MarsHomestead-Polymers.ppt.

Thelen, Ed. "M.I.T. - Apollo Guidance Computer." Ed-Thelen.org. June 2009. Accessed March 17, 2012. http://ed-thelen.org/comp-hist/vs-mit-apollo-guidance.html.

“Trichloroethylene." United States Environmenal Protection Agency. March 6, 2007. Accessed March 30, 2012. http://www.epa.gov/ttn/atw/hlthef/tri-ethy.html.

Ultimaker, Ultimaker 3D Printer. n.d., photo, https://shop.ultimaker.com/media/catalog/product/cache/1/image/800x6.

“US Center of Military History." United States Army. April 3, 1959. Accessed March 27, 2012. http://www.history.army.mil/faq/horizon/Horizon_V2.pdf.

Vinh Hoi Le Chau, Daniel Hon, and Sebastian Golze. "Humans in Space Introduction." Astrobiology: The Living Universe. 2000. April 3, 2012. http://library.thinkquest.org/C003763/index.php?page=human01.

Waymer, Jim. "Space Program's Environmental Cleanup Could Take Decades." Florida Today (Florida), July 31, 2011.

Weinberg, Michael. “It Will Be Awesome If They Don’t Screw It Up: 3D Printing, Intellectual Property, and the Fight Over the Next Great Disruptive Technology.” Public Knowledge. November 2010.

Williams, David R. “A Crewed Mission to Mars.” NASA. January 6, 2005. Accessed March 18, 2012. http://nssdc.gsfc.nasa.gov/planetary/mars/marswhy.html.

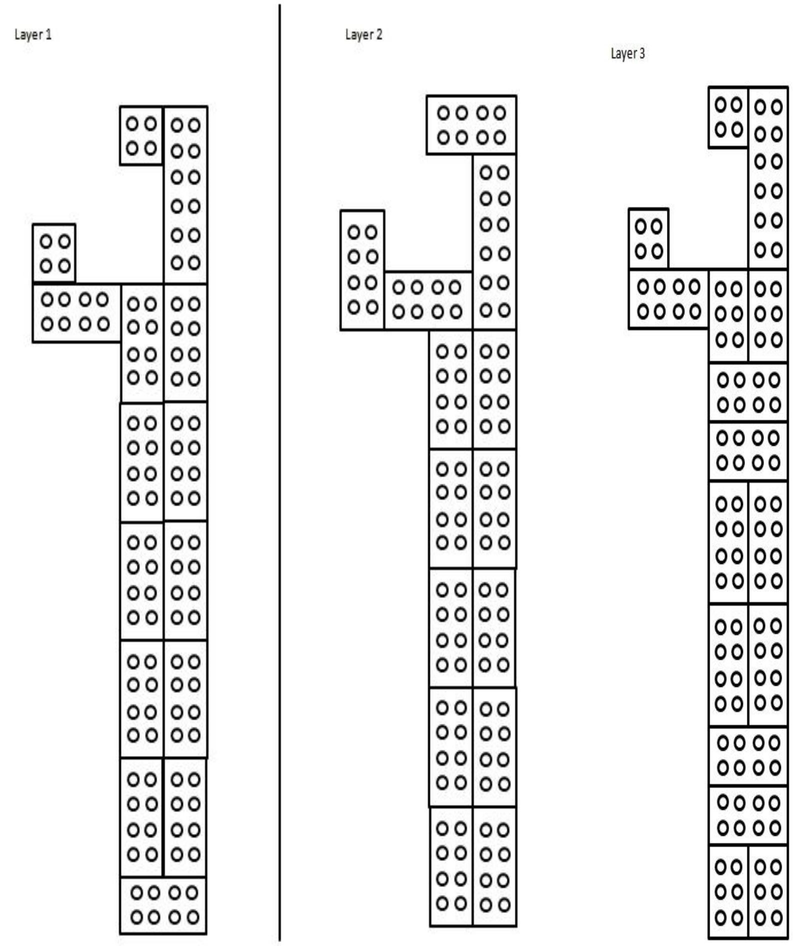
Yau, Nathan. “The Do's and Don'ts of Infographic Design: Revisited.” Smashing Magazine, October 21, 2011. http://www.smashingmagazine.com/2011/10/21/the-do%E2%80%99s-and-don%E2%80%99ts-of-infographic-design-revisited/.

Zubrin, Robert. The Case for Mars: The Plan to Settle the Red Planet and Why We Must. New York: The Free Press, 1996.

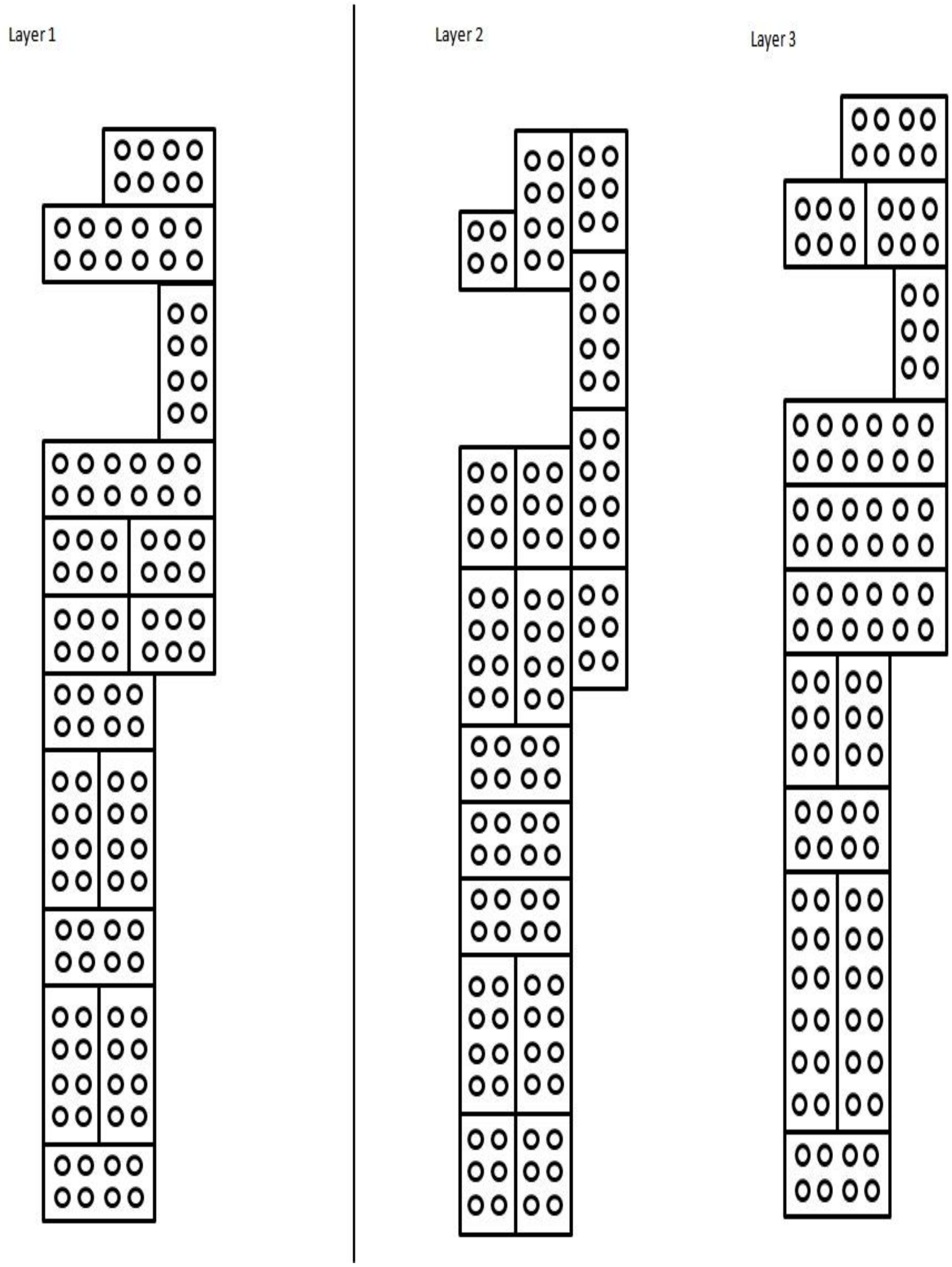
6. Appendix

6.1 Activity

6.1.1 Wrench



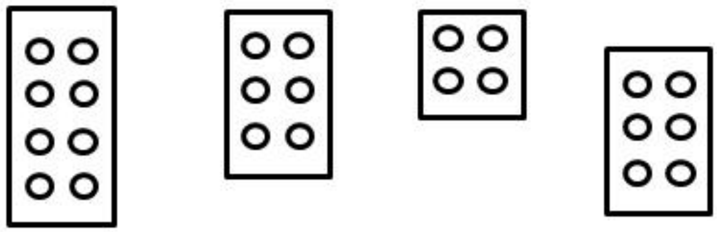
6.1.2 Monkey Wrench



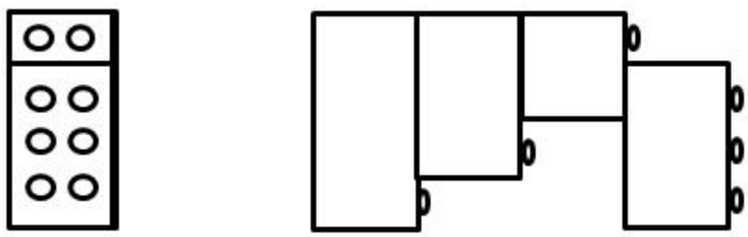
6.1.3 Hammer

Hook:

Layer 1 Layer 2 Layer 3 Layer 4

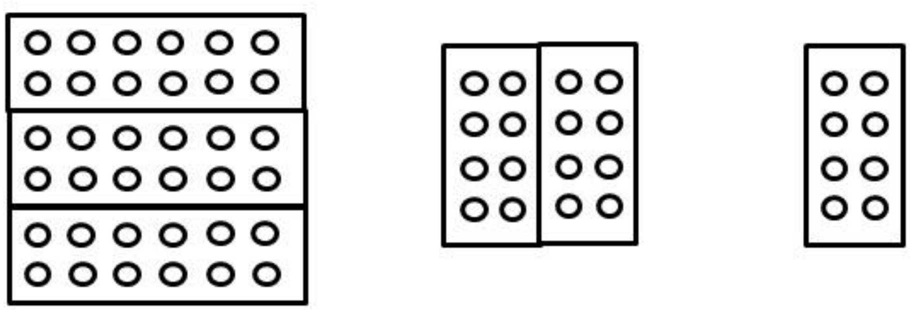


Assemble:

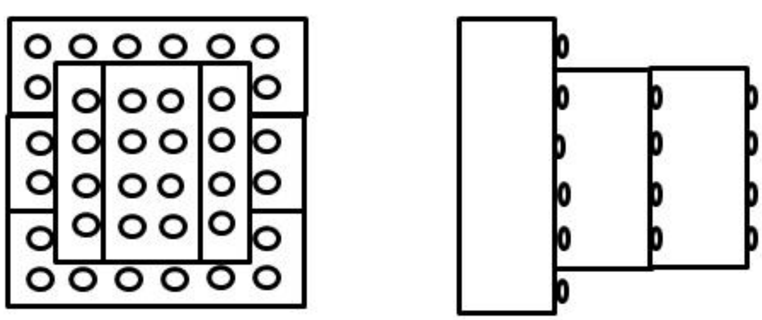


Hammer Head

Layer 1 Layer 2 Layer 3

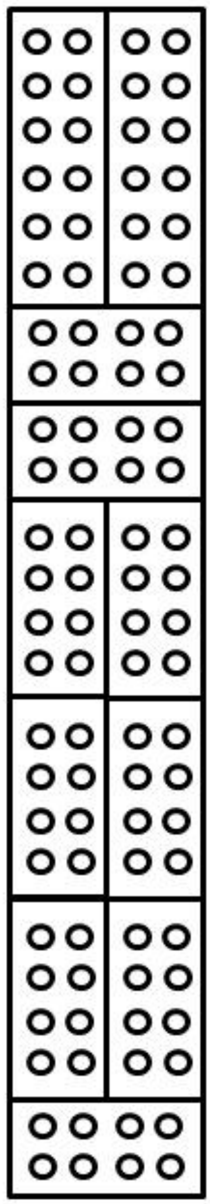


Assemble:

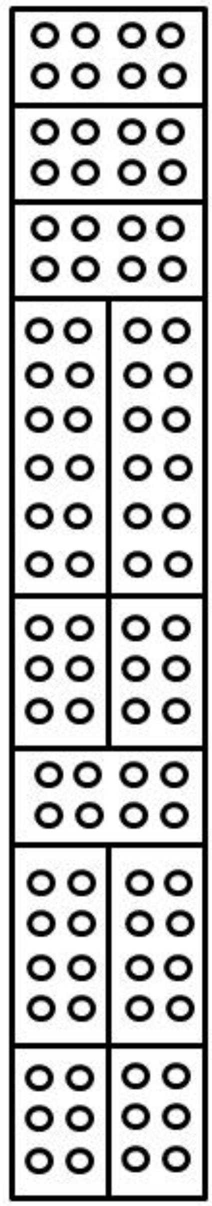


Handle:

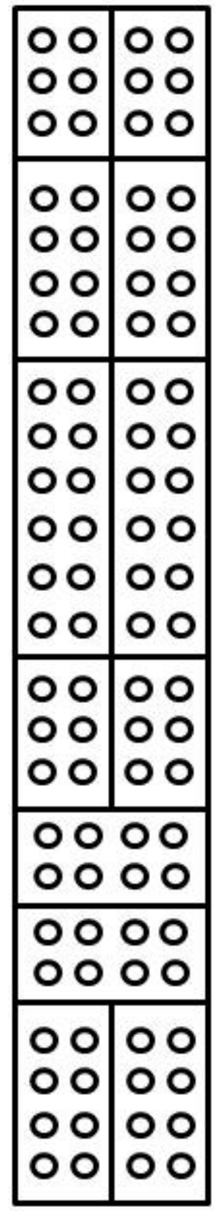
Layer 1



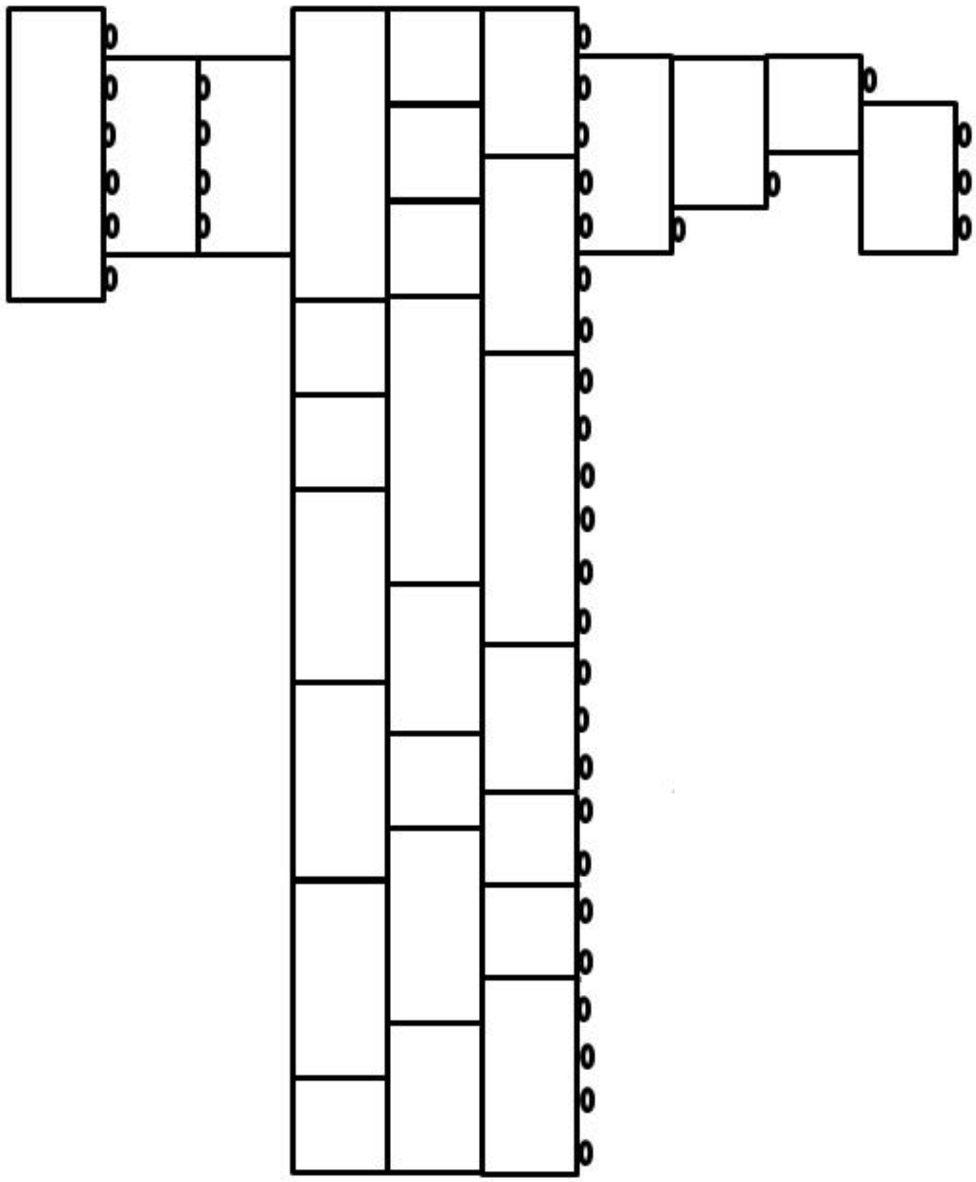
Layer 2



Layer 3



Part Assembly:



6.2 Rapid Prototype Requirements

WPI Rapid Prototype Guidelines

The RP machine is meant to be used for parts that cannot be easily made by other on campus methods. Parts that could be easily created on CNC machines, or standard parts that can be easily purchased, are not good candidates for the RP machine.

The Rapid Prototype machine prints parts in ABS plastic. There is no guarantee that your part will be water tight, especially if very thin. Because of the method the machine uses to layer the plastic, even thicker parts are still porous.

The minimum recommended wall thickness is 0.060" and the maximum build dimensions are 10"x10"x12 (height)", although if the part fills one of those dimensions exactly, the part may not build. The practical limitations are about 1/16" less than 10" in x and y directions, and about ½" less than a 12" height.

The Dimension SST has very good dimensional accuracy, with an error range of about +/-0.006".

IMPORTANT: Be aware that rapid prototyping does not mean instant. Parts generally take several hours to print, and depending on the queue it could take several days before your part gets in the machine. Also, depending upon the support material required, the part will need to spend several hours in the tank to dissolve any support material that couldn't be removed manually.

SUBMISSION:
(Failure to follow these guidelines may result in your order being rejected)

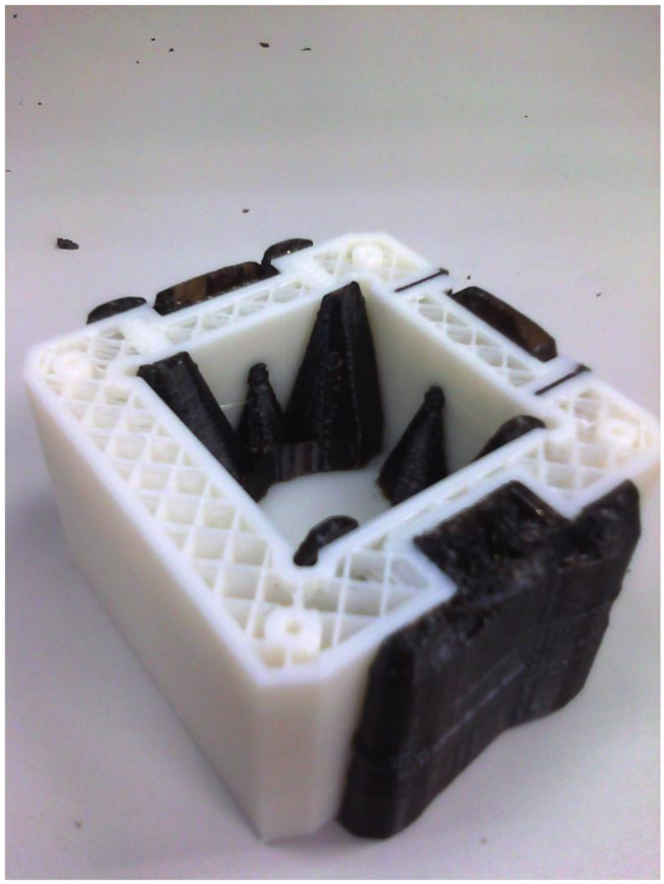
Be sure your parts are finalized before submission. Once submitted, the order will be processed and put into the queue. Any changes after the files are processed will move the resubmitted parts to the end of the queue, and will cause delays for the rest of the queue.

The file format that is submitted must be ".stl", which can be created from most CAD software. You can access instructions on creating the ".stl" file for printing from SolidWorks or Pro-E on the share point site: https://home.sharepoint.wpi.edu/academics/ME-PROTO. This is also the site which you should use to submit your parts.

When you submit your parts via the SharePoint site, please submit multiple parts via a single .zip file. DO NOT submit a different order for each part, if submitting all parts at the same time. Also, if you want multiple copies of a certain part, do not submit two identical files. Indicate the desired number of copies in the order description.

Be sure to specify when you submit your parts if you would like them printed in any particular orientation. (Be aware that anything circular in your model can only be perfectly circular if printed axially vertical. If you have two holes through your part in perpendicular directions they cannot both be perfectly circular).

Also specify the required strength of the part when submitting via the SharePoint site (in relative terms; I don't need exact figures), as we can print in various material densities to reduce material consumption. The lower density print (called sparse) creates a honeycomb-like structure in the interior of the part. The outside surface of the parts is in no way affected by the density change. See the next page for a picture of the cross section of a lower density part.



6.2.1 Colors

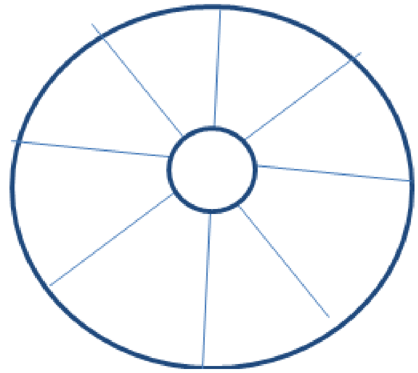
The ABS plastic is available in several colors: ivory, nectarine (orange), red, black, blue, and yellow. Please indicate in your order description during submission if it is important that specific parts be certain colors. Be aware that this may slow the printing of your parts, as the material in the machine must be changed for each different color. Typically the default color is ivory, however Ivory is not guaranteed if no color choice is specified. You will be notified if your choice of color is not available.

6.3 Concepts for Exhibit Design

6.3.1 Polymer Science and Chemistry

- Chemistry

- Atomic/Molecular level intro – use H2O as an example (2 hydrogen atoms, one oxygen), terminology: mer, monomer, polymer,
- Molecular Models – physical plastic models of H2O, CH4, Polymer, H2
- Examples of what polymers can make (daily life and no-so-daily life) – a wheel shown below, polymers in the middle circle, and everyday items around it i.e. furniture, clothing, etc.



- Create your own polymer activity – interactive, touch screen, visitors take the knowledge they have learned and create their own polymer, click and drag atoms and attach "*mers*" together

6.3.2 *Manufacturing and Products*

- Physical examples of Martian resources – Mars regolith and other materials found on mars in jars
- Info-graphic of plastic production on earth – plaque displaying pictures of earth materials and the process of how these materials are formed into plastic on earth
- Plastic Manufacturing – explain the process of forming plastic using the models. Number code the structure according to the step
- Models of manufacturing plants
- Terrestrial
- Extraterrestrial

6.3.3 *Fabrication and Design Engineering*

- Freedom of Design – show that you can make anything on the 3D printer, displays various items from simple to most complex. Explain CAD
- Fabrication
  - 3D printer (weenie) – interactive, will only be shown printing during the presentation,
  - 3D Scanner – only for presentations, its expensive and needs to be used by someone who is experienced with it

            - Monitor w/ 3D models – double display showing the software program for presentations, 5 min or less video of the printer printing the part when there isn't a presentation, text included in video.
    - Tactile 3D printed part – resolution comparison – difference between industrial and commercial. Have the visitors feel which item (one printed from an industrial printer, the other from the MakerBot) came from which printer.
    - Future Applications
        - Replication – show that you can make another 3D printer out of a 3D printer by displaying a half done printer where all pieces are 3D printed.
        - Construction of Settlement – explain that you can use 3D printers to help construct the Mars settlement
        - Sustainability – explain that you can use 3D printers to make life a bit easier on Mars, cost effective since it is expensive to ship out parts from Earth, and the window of opportunity is small

6.3.4 Mars Info

- About Mars (factual)
    - Facts & Background – and have interactive scale where visitors can see how much they would weigh on Mars.
    - Resources – explain what Mars has to offer.
    - Exploration – timeline of missions to Mars, rovers
- FAQs
    - Can we live there? – explain we can live there; we have the technology to do so. Pictures of futuristic settlement and settlers working
    - Can we get there? – explain that we have the technology to get there. possibly have interactive activity on touch screen on making your own rocket to get to Mars.
    - What can you make on mars? – explain that we can use the regolith to create plastic, drill ice to get water.

6.3.5 Why Settle Space

- Beneficial for Economy
    - For businesses- Economies of HUGE scale and beyond the bounds of our planet
        - Resources and trade
    - For everyone
        - Western frontier of the future
- Science advancement a la space race
    - Boosts earth economy via competition
    - Allows for scientific studies and discovery
    - Boosts innovation
- Offers space for human expansion
- Lunar Argument
    - Advantages
    - Disadvantages
- Martian Argument

        - Advantages
        - Disadvantages
    - IT’S COOL – popular culture icons, who wouldn’t want to be Commander Shepard or Captain Kirk
        - Step into the unknown.

6.3.6 *Life on Mars*

- The Settlement
    - Greenhouses
    - Power plants
    - Resource refining and manufacturing
- The people
    - Health and safety
- Robots and automation
- Connections with Earth
    - Communication back home
    - Shipments of needed goods & materials