A Proposal for an Educational Lunar Base Simulation Exhibit

An Interactive Qualifying Project Report

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Abstract

This project required us to take the Worcester Memorial Auditorium basement and repurpose it as an educational exhibit. The Worcester Memorial Auditorium remains an unused resource for the city, and the only way to resolve this issue is to repurpose the building for something that will benefit the city and its community. The educational exhibit was based off of the concept of the 2069 Lunar Base. The Massachusetts STEM curriculum framework was combined with extensive research on the concept of a lunar base in order to create an interactive and innovative simulation experience. Sub-exhibits were designed closely around major curriculum standards for fifth through eighth grade in order to attract educators and increase the chances that students will visit the exhibit with some previous exposure to the material. Each sub-exhibit was designed to mimic a portion of a lunar base while providing hands on learning activities and experiments. All of the sub-exhibits were designed in 3D in order to fully realize our vision and allow others to use it as a platform for expansion. Our execution of the lunar base exhibit combined theory and practice to create a flexible and dynamic educational exhibit that promotes learning and captivates students.

Table of Contents

Introduction

While Science, Technology, Engineering, and Mathematics, known as STEM, is gaining more and more traction with the educational community, there exists a lack of resources and innovative methods by which most educators can teach such a curriculum. With the emerging prominence of STEM, it can no longer be ignored, but focus still has not shifted away from standardized tests. There has been some progress in STEM education, but it is still not enough. Every effort must be made to help educators improve STEM education until it on par with the rest of the curriculum. The key to improving STEM education may not lie in the material, but in how the material is presented. STEM topics are unique as they often require lab stations, special equipment, or other preparations that may not yet be common or available to every school or grade level. There is a need for an interactive way to teach the STEM curriculum so that standardized test scores improve and students retain the material which they are taught. Focus must be placed on the creation of an experience that will enthrall students and make them life-long STEM learners.

Methods of teaching STEM topics are ever evolving. In order to inspire students and increase their effectiveness, educators are striving to expose students to engaging laboratory and educational experiences. These experiences and experiments must be pertinent and challenging while remaining at a level that is appropriate for the students' grade level and background. Many students benefit from tactile, "hands-on", learning methods. This puts students in the midst of the action, allowing them to solve problems and develop their intuition.

Our goal is to utilize a captivating simulation of the proposed 2069 Lunar Base in order to properly educate and expose students to many key concepts from within the Massachusetts Department of Education STEM Curriculum. This experience comes in the form of an educational exhibit broken down in sub-exhibits that allow students to learn through the use of interactive, hands-on, activities and experiments all while maintaining the illusion of exploring an actual lunar base. Our vision is to simulate an immersive lunar base environment in the basement of the Worcester Memorial Auditorium and to use the base's unique STEM properties to educate students about relevant STEM concepts using a kinesthetic approach to foster creativity and interest.

Background Information

Base Logistics

A 2069 lunar base after which this exhibit is modeled after presents some unique logistical challenges in terms of construction. The moon's unique environment makes both constructing and powering the base a calculated and costly endeavor. The first logistical challenge is importing any necessary material from the earth to the moon. This is one of the more costly parts of building the base, as anything imported to the moon is not only expensive but is charged by weight. The high cost per unit weight of importing material to the moon makes it a less than ideal option for constructing an entire lunar base.

The most effective way to build a lunar base is to use materials local to the moon. Lunar soil, regolith, is comprised of a number of elements and compounds that could be refined into raw materials and used in the construction of the base. This would be the most efficient and cost effective way to build a base after initial, temporary, settlements and facilities were established. The base would also need to be constructed out of materials that could withstand the harsh conditions of the moon. These conditions range from extreme variations in temperature to radiation to lower gravity and virtually no atmosphere. A base would need multiple layers, each with its own purpose to serve such as structural rigidity, insulation, protection from space hazards, etc.

Because of the harsh environment on the surface of the moon, a lunar base would most likely have to be under ground. Building the majority of a lunar base underground would give it protection from radiation, micrometeorites, cosmic rays, and solar wind particles. These hazards are particularly harsh on even the best of building materials which is why a couple of yards of regolith, at the very minimum, are needed to protect the base. The problem with building an underground base is drilling on the moon. The lack of atmosphere on the moon makes processes like drilling, which rely on earth's atmosphere to dissipate heat, extremely difficult. Without any atmosphere, the heat caused by the friction of drilling would build up and eventually cause the drill bit and the rocks to fuse together. This eliminates drilling as a serious possibility. However, the moon's lack of atmosphere does have one advantage. The moon's surface is covered in craters from meteor impacts. These craters are perfect locations in which to build bases below the surface of the earth as the "excavation" work has already been performed. This also eliminates the need for blasting as it would have catastrophic effects as a result of the moon's lack of atmosphere. Even after the construction logistics were resolved, there exists a need for an effective way to remove lunar dust from anything returning into a lunar base from the lunar surface. Traditional air locks would not be effective enough to remove all of the dust. While other methods exist, the water airlock in which anything returning from the surface must be completely submerged in water is the most simple, elegant, and effective.

Another consideration in building a lunar base is powering said base. The only two viable methods of providing power for a lunar base are nuclear or solar. Using solar power to power a lunar base has a number of distinct disadvantages. The main disadvantage is the large cost associated with transporting solar planes to the moon. In order to create enough power for the entire base a large number of large solar panels would be necessary. The cost of transporting these panels to the moon would be astronomical. This cost coupled with the abuse that the solar planes would be subjected to on the surface of the moon quickly bring the feasibility of a solar powered moon base to zero.

The most effective method of powering a moon base is nuclear power. Nuclear power has been used in space applications since the 1960s. Nuclear power is extremely advantageous because of its flexibility to function in even the most adverse environments. This makes a nuclear power source perfect for lunar colonization as it will be reliable and hold up to the abuse that it's likely to face. In addition to being used as a source of electricity, nuclear power can also be used as sources of heat. This is crucial to creating a habitable lunar base as a form of heating would be necessary to keep the base temperature regulated. Nuclear fission, the process of splitting the nuclei of atoms in a reaction that releases heat, is an ideal method of powering a lunar base. It provides an excellent power to weight ratio which is ideal in terms of importing any necessary equipment to set up a nuclear power plant. The one drawback of fission is that a fission plant requires significant radiation shielding as it irradiates the walls that enclose it. The simple solution on the moon is to bury the reactor or place it inside a crater. This is an elegant solution in terms of protecting the plant from the harsh surface conditions, creating radiation shielding, and protecting the base against any possible accidents that could occur. A fission reactor has the ability to cover a lunar base's electrical as well as heating needs. Fission plants are long lasting and are usually designed to operate without human intervention.

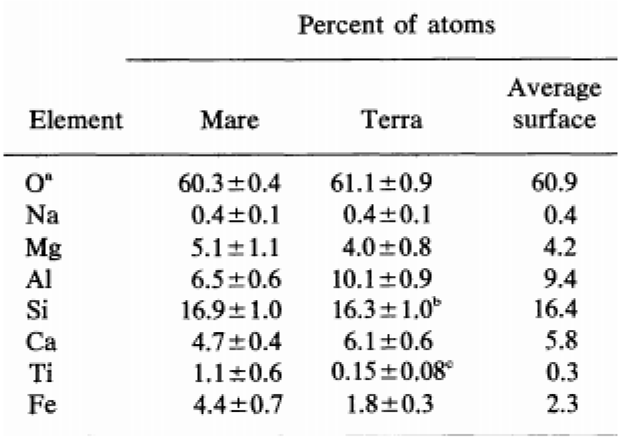
The alternative to a fission reactor is a fusion power sources. The main problem with a fusion power sources is that, to date, none exist. While this is a seemingly impassable road block, the moon contains significant quantities of what has long been proposed as a fuel for nuclear fusion, helium-3. Helium-3 is a rare isotope that is not found anywhere on earth. It is deposited on the moon, due to its lack of atmosphere, by solar winds. Fusion technology has not yet been developed to the point where it could be used as a practical power source, but in the future the moon is equipped with all of the apparent necessities to support a nuclear fusion power source. This power source would be preferable to fission as it would not irradiate the reactor walls like a fission plant.

Regardless of which method of nuclear power is used to power a lunar base, nuclear power is the most effective in terms of both cost and power per size. Nuclear technology has come very far in past decades making fission both safe and compact. The benefits of a lunar base that runs on nuclear power clearly outweigh any of its potential drawbacks. Nuclear power is the clear choice for lunar colonization, especially if there is any progress in the field of nuclear fusion.

Lunar Regolith

The regolith is one of the most important parts of the moon. The regolith is the part of the moon that would need to be utilized to build a moon base and also to sustain it. Most of the lunar regolith is made up of a few different elements. Between oxygen, sodium, magnesium, aluminum, silicon, calcium, titanium, and iron these eight elements account for over ninety-nine percent of the chemical make-up of the lunar regolith. The breakdown of the concentrations of these elements is provided in Table 1 below.[1]

1: Turkevich, A.L. "The average chemical composition of the lunar surface." *Proceedings of the Lunar Science Conference* 2 (1973): 1159-1168



Element	Percent of atoms		
	Mare	Terra	Average surface
O[a]	60.3±0.4	61.1±0.9	60.9
Na	0.4±0.1	0.4±0.1	0.4
Mg	5.1±1.1	4.0±0.8	4.2
Al	6.5±0.6	10.1±0.9	9.4
Si	16.9±1.0	16.3±1.0[b]	16.4
Ca	4.7±0.4	6.1±0.6	5.8
Ti	1.1±0.6	0.15±0.08[c]	0.3
Fe	4.4±0.7	1.8±0.3	2.3

Table 1: The percentage of each element by atom in lunar regolith.

The lunar regolith would be processed and then each element could be used to perform a necessary function. Many of these elements would go towards the formation of building materials, while others would be used for human needs, such as oxygen to breathe. Also, possibly being about to grow plants in a greenhouse using regolith is a huge task that would hopefully be achieved by 2069.

Robots

Man has always looked toward the sky. Throughout the years man looked to it for warmth, navigation, understanding, and inspiration. As technology evolved, the sky, once so far away, started moving ever closer. Over a century after the first powered flight, man had become master of the skies. Political reasons made the moon a target during the onset of the Cold War, with the last two superpowers investing money and time into improving space technology and making manned flight a reality. Neil Armstrong became a symbol of space conquest when he became first man to land on the moon in 1969. This laid the ground work for lunar robotics. The world's curiosity continued to grow fueling innovation that paved the way for further exploration. Countless expeditions have sent robots into space to explore, understand, and discover all of the questions mankind had about the universe around them.

The first robots to reach the moon were part of the Russian Lunokhod program. They landed on the moon roughly a year after Armstrong. Lance Armstrong may have been the first man on the moon, but the Lunokhod 1 rover made history as the first robot to land on the moon. Lunokhod was a remote-controlled rover, meaning that it was operated by signals that it received from Earth. Lunokhod's design incorporated eight wheels, an array of cameras and antennas, and the ability to perform complex analysis and beam the information back to earth. Since it was exposed to all the hazards of space, special measures were taken to ensure that the motors and systems functioned even in the harshest conditions. The motors were packaged in pressurized cases connected to the drive wheels. This was due to the technological limitations of the motors, which could not operate in a vacuum. To this day, they still cannot operate in a vacuum. The heat from radioactive decay was also used to keep the internal components of the machine from freezing due to the extremely low temperatures prevalent in space. There were also quite a few hi-end cameras attached to the spacecraft in order to survey the moon and transmit images back to Earth. Aside from being the first of its kind, the Lunokhod 1 also lasted for a record-breaking total of three hundred and twenty-two earth days.

Literature Review

IQP: A Proposal for an Educationally Interactive Exhibit based on a 2069 Lunar Base

Students in Worcester have been struggling for a few years in regard to their learning of the STEM curriculum given from the Massachusetts Department of Education. Last year another IQP group recognized this, and tried to find a way to solve the problem through the use of a moon base exhibit based in the Worcester Memorial Auditorium. The IQP team looked at previous results of the Massachusetts Comprehensive Assessments System (MCAS) for

Worcester schools and found that 42% of the students taking the test scored in the “needs improvement” range or lower. To combat this alarming trend, the team believed that new teaching methods could be necessary to provide students with a better way to learn the material. Traditionally, opposition to STEM fields was because of the concepts being overly technical, causing difficulty in understanding.

The goal of the team was to use new teaching methods to provide a boost to the understanding and interest in Worcester students, specifically those between fifth and tenth grade. In order to accomplish this goal, the team analyzed some of the ways teaching has evolved in the past few years. They concentrated on how the internet is now available to be utilized in education, especially resources such as, Khan Academy, YouTube, and games/puzzles. To draw attention and apply these new methods, the team designed a lunar base exhibit, highlighting these new teaching techniques, while also engaging students in an interesting and unique way.

Our IQP group decided to shift the focus away from incorporating new teaching strategies, to exhibits based directly on the STEM curriculum that would engage students in different ways. Our Lunar Base Exhibits would be based off a possible component of a Lunar Base or its function, while also simplifying it down to meet the curriculum requirements. By focusing on the curriculum, we believe that more Worcester area teachers would want to incorporate the exhibit into their class, while also providing a new way for the students to look at otherwise mundane topics.

IQP: A Lunar Base Exhibit Proposal

Previous IQPs have found evidence that math and science were not particularly popular subjects among students in the Worcester Public School system. In response to this alarming statistic, a program was launched to reform the curriculum of 5th graders in order to generate an interest in STEM subjects. The goal of the program was to counteract the negative feelings generated by bad standardized test scores, by either eliminating them or generating more interest in the subject matter. By implementing new methods of teaching, educators hope to spark interest in STEM in order to replace the 25+% of STEM experts that will be retiring in the next 3 to 5 years. (Warner et. al)

The curriculum was altered this year in order to stimulate the young minds with twenty hours of extra lessons. These lessons encompass subjects that are spread throughout five chapters that the students do not have to directly read. Information gathered from Worcester public schools' observations was used to address the challenge of living and working in a space environment without using the need to read from a textbook. (Warner et. al) This was accomplished through the use of hands-on activities to keep the students entertained and excite them about learning.

Brainstorming, Background Research, and Preliminary Design

Brainstorming

The first point of order that needed to be discussed at the beginning of this undertaking, A-Term 2013, was the curriculum portion. While it was not understood at that point how big of a roll it would play, the curriculum that the exhibits are based on turned out to be one of the most important and guiding parts of the entire project. What the team was left to realize was that if the exhibit does not stick tightly to the curriculum, then there will not be enough interest in it from educators. Initially, the team tasked its members with finding the curriculum for Worcester Local schools, as that was "closest to home" since all of the members are WPI students. Each team member was assigned a grade, 4 grades (5^{th}-8^{th}) divided up amongst 4 team members. The task at hand when starting this project was to research the curriculums and come up with some ideas based on the curriculum. This was a main focus but not the only point of discussion. The project criterion, while not completely lucid, was another topic of early discussion. The main goals of the team were as follows: Create an educational lunar base exhibit for grades five through eight, mimic a lunar base/moon environment and conditions in the exhibit, have the entire lunar base exhibit take 1-2 hours to go through, ideally create the exhibit to be located in the basement of the Worcester Memorial Auditorium, give the students a presentation in the little theater before the entered the exhibit, and create a very hands on experience so as to explain STEM (Science Technology Engineering & Mathematics) principles in a fun and understandable way.

The team initially focused on some key principles of lunar living such as: robotics, physics, chemistry, gravity, waste disposal, sustainability, dangers of moon living (radiation, oxygen supply), food sources, health risks, and what materials would be used to create a lunar base. Other topics that needed to be addressed included conceptual questions about a lunar base. They mostly consisted of feasibility issues such as how the base would be paid for, what it was to accomplish, and what would be the point of having a lunar base. While focusing on the theoretical moon base that the exhibit was to be created after, there were also ideas and suggestions about the actual exhibit. They included things such as transitions, danger simulation, robotics, and zero gravity and robotics simulations.

As curriculum research went on, ideas about exhibits slowly began to develop. Among the first was a robotics room, a food/plant growing station, and an exhibit about the weight of objects on the moon as opposed to earth. These ideas were very rough and in their earliest stages, based on little more than rough ideas of educational concepts that could, perhaps, be found in the curriculum.

While doing lunar living and curriculum research, questions about the logistics of the exhibit as a whole came up. These questions, yet to be resolved, included the number of students per trip, how to keep all grade levels entertained, if exhibits that vary based on grade level could be constructed, and what sort of decorations would be used in creating the overall exhibit.

The group, once again, touched on the question of if the base could be made self-sustainable. This time the idea of exporting a lunar resource from the moon to the earth for profit came into play. It seemed as if this could allow the base to pay for itself, contingent on the team finding a feasible export and method of exportation. The team also received its first external inspiration for the exhibit. This came in the form of the Museum of Science and Industry in Tampa, Florida. This particular museum had an exhibit called “Mission: Moonbase,” which was very similar to the project that was being undertaken by the group. The only notable differences were its small size and lack of educational complexity, the latter of which became something that the team tried to prevent in this project.

The small size was not an issue for the team, as the Worcester Memorial Auditorium Basement was massive. However, none of the team members had ever been inside of the Auditorium and some were not even particularly familiar with the building. To remedy this problem and give the team a greater “vision” of what they were working with, it was resolved that a tour of the auditorium should be sought.

Initial dimensions for the exhibits were discussed by the team and it was agreed upon that there would be eight exhibits, approximately 4,000 square feet each (This was based on the initial assumption that the Auditorium basement was 37,000 square feet in area). It was decided that the Lunar Base exhibit would hold a total of 120 students and their chaperones/teachers and each exhibit would take around 30 students at once. It was also noted that the little theater had more than ample seating to accommodate the maximum number of people per visit.

Exhibit ideas emerged with six exhibits and two research concepts coming to light. The six exhibits were as follows: a Greenhouse exhibit, a Robotics exhibit, a Zero-Gravity Exhibit, a Mission Control exhibit, a Habitation exhibit, and a Power Generation Exhibit. The two topics of research were recycling and 3-D printing. These exhibits and topics were divided up amongst the team members for further research.

In the meantime, the curriculum portion of the project took a turn away from the Worcester public schools curriculum when the Massachusetts Department of Education STEM Curriculum Framework was introduced to the group by one of the members. This curriculum framework would soon come to be the educational backbone of the project. The pertinent parts relating to the exhibits have been included in the Appendices. The curriculum was taking shape but the team also wanted to research a number of other important concepts. Among these were: dangers of lunar living, safety procedures, the location of the base, and the use for regolith (lunar soil). Out of all of these potential topics, the location of the base was quickly put to rest as the team agreed upon as being in a crater on either the north or South Pole of the moon.

Research

Research for the exhibits and other concepts began to come together. The Lunar Green House prototype done by the University of Arizona was to be used as a model for the Greenhouse exhibit. It made use of recycled materials, and could help cement the location of the base as the north pole of the moon since it relied on ice mined from for the lunar craters of the North Pole. Habitation problems and logistics were identified, the majority of them focusing on keeping inhabitants healthy (food, exercise, waste disposal, air quality, etc.). Entertainment came up as a question but was not pursued far beyond practical ideas for entertainment. In order to keep lunar inhabitants health, however, there was much work to be done. Lunar living presents dangers such loss of muscle mass from the low gravity and a loss of bone density. These could be combatted by protein supplements or protein rich foods such as beans. Another possible solution would be the use of steroids in order to help slow down muscle mass and bone density loss. Exercise was also a practical alternative, but relied on logistics such as strapping down base inhabitants to equipment to counteract the lack of gravitational force. The air quality also had to be monitored and taken care of either with the addition of plants around the base or a filtration system, most likely both.

Robots presented an interesting discussion as their uses are virtually limitless but, the group agreed that there should be an even balance between the use of robots and humans to perform tasks. Some of the possible jobs for Robots included communications, cleaning, and lunar surface tasks.

Gravity on the moon was researched and came up in the majority of topics, exhibits, and ideas in terms of logistics and solutions to problems that it caused. Some major issues that would have to be taken into consideration were the long term effects of reduced gravity, dealing with the fact that everything weighed approximately 1/6 of what it did on earth, the lack of atmosphere, and lunar soil interaction. Key construction logistics problems were that based on the gravity, lunar soil, regolith, does not settle like rocks. It is jagged and can easily cause contamination. Drilling of any sort, especially since the base would be subterranean, would also present a problem. The lack of atmosphere on the moon would not allow the heat caused by drilling to dissipate as well, causing many issues which would make it very hard to justify the feasibility of drilling.

The mission control exhibit was expanded upon and it was decided that it would look like an "earth mission control" that is popularly depicted in most space movies. It would feature rows and rows of computers that could be used for all kinds of educational activities and for more than one of the other exhibits including robots, the greenhouse, the habitation, and anything to do with the lunar surface.

Nuclear power was researched and explored in depth. It came to light that nuclear power was one of the most feasible ways of powering a lunar base. It would be more beneficial than solar power because, depending on the placement of the base, the panels would not always "see" the sun. Batteries to store solar power were also deemed as not very feasible because of their size and weight, especially when taking the cost of transporting them to the moon into consideration. A nuclear power plant would also be smaller than a solar plant and work well in virtually any condition that the moon could offer. By this point in time Nuclear Fission, the process of splitting atoms to generate heat and electricity, has become developed and safe technology and would be perfectly acceptable for moon use. With further research and development, nuclear reactors could also be miniaturized to the point where they would become the most feasible option period. Even in their current standing nuclear plants would be feasible because of their capacity to be buried, which not only would protect them in adverse conditions but make them extremely safe.

Issues with lunar logistics and regarding lunar dangers were researched and the main problems were found to be with the temperature variation and lack of atmosphere. The temperature of the moon can vary anywhere from -200 degrees Fahrenheit to +200 degrees Fahrenheit. This extreme variation needs to be taken into account when constructing anything that would be exposed to the lunar surface or on it as temperature can aid to the majority of material and design failures, brittleness in particular when discussing freezing temperatures. The lack of atmosphere also does nothing to stop meteorites, other debris, or solar and cosmic rays. All of these things would have to be protected against when doing any sort of design/construction that was above ground or would be brought up to the lunar surface at any point.

Background research, organization, and preliminary exhibit design continued, but the team was also faced with some other potential problems that it might have to discuss or resolve. The main questions were in regards to the logistics "behind the scenes" of the exhibit as well as the financial aspects and feasibility of the exhibit. The exhibit would need staffing and the exhibits would require a substantial amount of technology. This was something that would have to be addressed along with what the budget for a lunar base exhibit like this would be/what it would cost, assuming the auditorium was reserved for this exhibit and did not factor into the costs.

The team also discovered a document in which there existed the most current blue print of the Memorial Auditorium's basement that could be found after extensive internet research. The blueprint would be used in order to design the two dimensional, "bird's eye," depiction of how the lunar base exhibit will be laid out and what size it will occupy. A copy of the blue print is included in the Appendices along with a collection of annotated sources that make up all the background research accomplished. Before the end of the term, the team also met with a number of speakers, all of which contributed ideas, concepts, and criticisms to the project.

Speakers

Marc Andelman met with the group to discuss the biological, food, and greenhouse aspects as related to space and space habitation. Andelman was especially informative in regards to the different types of plants that could easily thrive in space environments, especially C4 plants which can thrive in carbon-dioxide rich environments. Some of them were purposed for food while others were used as raw materials. The most pertinent plants were quinoa, cattails (a C4 plant), sunflower seeds and hemp. Quinoa (high in protein) and cattails can be grown easily and are used for nutritional value. Hemp, while having illicit connotations, is an extremely useful raw material from which almost any fibrous final product can be made such as clothing, rope, paper, etc. Cattails can also be used for their raw materials and sunflower seeds can be used in the production of rubber. This proved useful in possible ideas for what the greenhouse might contain.

Brian Moriarty discussed STEM destinations as visual resources and considerations for design of a lunar base exhibit. The visual resources portion of his lecture added gravity to the point that if this exhibit was to thrive it must be very visual and technologically advanced as well as being hands on. This is a point that was incorporated into the final design of the exhibits. Moriarty also touched on infrastructure and behind the scenes considerations of the exhibit. Some worthwhile ideas that are still in the process of being incorporated into the exhibit are conference rooms and classrooms. Considerations like maintenance facilities, restrooms, coatrooms, and employee services were already discussed but brought to the forefront of the team's discussion as aspects that will be included in the blue print. The biggest point that Moriarty drove home was that the exhibit should strictly follow the Curriculum Framework or else there would be very little interest in the exhibit since teachers focus on teaching MCAS/curriculum material and the time allotted for field trips is already extremely limited. Moreover, there should be some focus on what the students know before they visit the exhibit and how much or what they retain after their exhibit. This is dealt with towards the end of the final exhibit design process.

Bruce Mackenzie, founder of the Mars Foundation, discussed Lunar Resources and Space Travel with the team. The major contribution that came out of his lecture was the concept of the water air-lock. It was introduced to the team by Mackenzie and taken to the next level and turned into an interactive exhibit activity via the fluid mechanics knowledge and experience of the team's engineers. Mackenzie also helped the team to answer questions regarding power and financial feasibility of a Moon Base. Helium 3, an isotope of Helium found in abundance on the moon but not on earth, could be used to power the nuclear power generators needed to sustain a moon base. It could also be exported to earth for profit as there is enough on the moon to guarantee the world tens of thousands of years of fuel for nuclear power.

Dan Benoit, an architect, commented on the use of the Worcester Memorial Auditorium for the exhibit and its rich history. The group decided that this would be used in the project as it is important to build upon and exploit any potential benefit that exists from using this location for the exhibit. Reusing the auditorium while reviving its rich history and anything it might have to offer, like the memorial room, would make it more likely to get the support needed to have the building renovated and put to new use.

Paula Proctor was the final person that the team met with. She is an educator and formal principal of the Elm Park School. Her major contribution was giving the team insight as to the learning processes and abilities of the exhibit's student audience. She also related an important "top down" approach to relaying educational information. The team members integrated her ideas of starting with the large, possibly complicated, concept and continuously making it smaller, more detailed, and easily understandable until it would reach the level of the audience being exposed to it. This was in important concept that relied on an "upside-down pyramid" way of thinking to take difficult higher education topics and bring them to a grade appropriate level. With that the team finished A-term of the project with background research completed, preliminary exhibit design underway, and with solutions and answers to the vast majority of difficulties, challenges, and questions that came up.

Exhibit Design

The second portion of the project after the preliminary project design and the background research was the full scale exhibit design. This was the period where the most trouble was encountered since it was initially difficult to get all of the exhibits moving in the proper direction. The number of exhibits initially established at eight dropped down to five. Four exhibits that were not set in stone and a mission control exhibit which was decided upon from the beginning. The other exhibits went through numerous changes in concept or scope before the final ideas for each of the exhibits were agreed upon by all of the project team members.

While working on the exhibits it was decided upon that each exhibit should be allotted approximately 30 minutes for a total time of 3 hours for the whole lunar base exhibit. It was also decided that each exhibit should take up 5000 square feet or less, resulting in a cumulative 30,000 square feet or less. The lunar base exhibit would take up to 150 students and all their chaperones and teachers. Each individual exhibit would take approximately 30 students and all their chaperones and teachers.

The team initially planned to create exhibits around the research done on the moon and lunar base concepts. While this research was still pertinent and all of the exhibits in their final stages are based after the concept of a lunar base exhibit, there was a large shift in the way in which the exhibits were created towards the end of B-term. The exhibit design towards the beginning was going smoothly, but then a major problem arose that put a halt to the progress until it was addressed. The exhibit concepts created in preliminary design were good on paper and had research to back them, but could not be fitted to the curriculum framework once they were nearing any sort of progress.

This caused some exhibit concepts to change entirely while other exhibits kept the same concept but dramatically changed their scope. At first, it was a difficult process because the team was not sure how to fix the lack of conformity with the curriculum framework. After a fair amount of struggling and little progress it was agreed upon that the exhibits would be revamped, a change based almost entirely on the STEM curriculum framework. The concept of designing the exhibits around the curriculum, rather than trying to fit the curriculum to the exhibits proved to be much more efficient and beneficial in exhibit design.

By using the curriculum framework as the basis for project design, the team was able to progress to resume progress and create quality exhibits that closely followed the curriculum framework. It was decided that any portion of any exhibit that did not follow the curriculum framework would be scrapped. It was also decided that any exhibit that could not be closely related to the framework would be scrapped. This made sure that the team had a clear and pertinent direction to move in. It also ensured interest in the exhibit from educations since followed the framework almost as closely as most of the teachers taught to the framework.

Once the concepts for each exhibit were finalized, work began on the proposals. The proposals started out as small, fairly basic, all text proposals. As we continued to work on them and meet to discuss, critique, and improve them, they began to grow. The proposals started to get more and more elaborate as the team collaborated to make each exhibit proposal better and better. The group also decided that it was necessary for each proposal to use pictures and graphics to further explain and clarify the exhibits. This resulted in the introduction and continued addition of graphics in each proposal, making each exhibit concept easier to understand and more visual than theoretical.

The description of each exhibit and its respective activities and logistics was also stressed by the team to the point where each proposal was improved with lengthier and more in depth descriptions, leaving nothing to question. At this point, only a few final additions were missing from what would be polished and completed proposals, ready to be edited into a contest entry. The need for a realistic, high-tech, and “dressed up” environment that would mimic a lunar base and appeal to both students and educators was expressed. The team agreed that it was a “must” and proceeded to update the exhibits with new, appealing, descriptions of the exhibit decoration/environment setup.

The time of the exhibit was extended an extra hour to four hours in order to accommodate the extended Robots exhibit. This was a result of a team decision to keep the length of the exhibit, even though it was far above the original 30 minutes allotted for each exhibit. This was done as a result of the complexity of the exhibit and the merit it showed in attracting and keeping students interested.

The final addition to complete the proposals was brought up numerous times, but once again became pertinent as a result of the need to produce an entry for the lunar base exhibit contest. The team has spoken of creating three dimensional representations of each exhibit layout. It was agreed upon that this would be a necessity for the contest entry. The method by which the three dimensional graphics were going to be created was a topic of debate. In the end Google’s Sketch Up software was introduced to the team by one of the members. After discussing the benefits and feasibility of using the software, it was decided that this software would be used to render a three dimensional graphic depicting the layout and environment of each exhibit. Work has started on these graphics and the proposals will be polished and complete after the graphics are completed and appended. They will be completed soon, which will allow for the exhibits to be combined into a contest entry.

The Little Theater

The Worcester Memorial Auditorium has a small usable theater. The Little Theater has roughly 617 seats. 325 of those seats are on the main floor part of the theater. All of the students (around 150) and chaperones attending the trip would be able to fit quite comfortably. The group decided that prior to entering the Lunar Base Exhibit; the students would enter the Little Theater for a short movie depicting a trip from the Earth to the Moon. The idea for an introductory movie was somewhat inspired by the Mission Moonbase exhibit at the Museum of Science and Industry (MOSI) in Tampa, Florida. There, they have a large screen on the floor which shows a downward view of a space shuttle leaving the Earth's surface, traveling through space, and landing on the Moon's surface. The movie shown in the Little Theater will be similar, but the view will be from the cockpit of the space shuttle. The shuttle will take off from Earth, travel through space for a little while with a speaker telling them what to expect once they arrive at the Lunar Base, and land on the Moon at the location of the base. The speaker will tell them the location of the base, mention the dangers of being on the surface of the Moon and that they must get to the base quickly after landing, and mention that they will travel through an airlock to enter the base. Then, the students and chaperones will exit the Little Theater, head down to the basement of the auditorium, enter the exhibit.

Moon Walk Exhibit

The Moon Walk exhibit did not start out anywhere close to what it is at this point and time. Originally, before the final concepts for each exhibit were laid out in stone, it was supposed to be an exhibit based on lunar logistics/dangers and possibly nuclear power. This concept was originally derived from the background research done regarding moon bases and life on the moon. The initial approach in setting the concepts for the exhibit was based largely off the team's background research. But, once the initial work on the moonwalk exhibit began, it was clear that the background research topics were not particularly well suited for an educational exhibit using the fifth through eighth grade STEM (Science. Technology. Engineering. and Mathematics) curriculum set up by the educational department of the state of Massachusetts. This presented somewhat of a problem for quite a while as the direction of the project and its exhibits was suddenly very cloudy. After a fair amount of discussion and some necessary decision making, it was agreed upon, with time running out in B-Term, that the exhibits would be revamped. The new concepts for the exhibits would stray away from our extensive background research, if necessary, in order to stick to the STEM curriculum.

From this decision the beginnings of the Moon Walk exhibit was created. The initial idea that the exhibit was based upon was a "moon bounce" of sorts. This was an idea thrown around by more than one of the teammates over A and B term, although it had not particularly led anywhere. It was only after the decision to make the exhibits based off of, more or less, the learning standards in the STEM curriculum that the learning standard of, "the difference between weight and mass, and how the acceleration due to gravity affects mass," was applied to the "bounce" idea. Initially it was brought up as a simulation using some sort of harness, ropes, counter-weights, etc. However, that was not deemed to be easy or particularly feasible, especially for a large amount of students. That idea was eventually scrapped for a lightly "trampoline-like" surface, which would allow students to jump slightly higher and simulate a small degree of weightlessness without creating any problems due to the constraints provided by the basement's ceiling height. After this idea was set into stone, some logistics were applied to it and the whole activity was planned out.

Working off of the "moon bounce" idea, the idea of a lunar surface walk was explored further. This is where the idea of similar objects that were weighted differently came into play. It was another idea tossed around during both A and B Term, but it did not see its fruition until it was applied to the Moon Walk exhibit. The "difference between weight and mass" learning standard was seen as something that could be reinforced via the introduction of "acceleration due to gravity" on its own. Luckily the STEM curriculum featured a learning standard that was along the lines of, "Contrasting the properties of objects on different planets, including the weight as a result of the acceleration due to gravity." This learning standard was a perfect complement to the activity of using identical objects with different weights to contrast the weight of an object on the moon vs. on earth. It first the activity was rather vague, not particularly specifying objects, and having the students do nothing more than pick them up and put them down. This was seen as interactive but not particularly appealing. This is where the decision to make the objects into sports balls came into play. The activity would feature identical sports balls with one weighing 6 times the weight of the other. This would allow the students to "feel" the difference between the weight of an object on the moon vs. on the moon in a more attractive manner. The students could play with/toss the balls back and forth making the activity entertaining while bringing the apparent difference between the weights front and center. After the activity was made appealing, the logistics and entirety of it was planned out.

The third part of the exhibit, the water air-lock, came about as an idea presented to the group by speaker Bruce Mackenzie, an MIT alumnus and founder of Mars Foundation. Mackenzie introduced the idea of a water airlock and it caught on as it was based on a familiar fluid mechanics concept that was recognized by one of the Aerospace Engineers in the group, Bernoulli's Principle/Equation. As this is a more advanced concept than usually taught at the fifth through eighth grade level, it was initially a bit difficult to nail down a learning standard to fit it. But the water air-lock was such an in innovative and interesting concept that it was included using one fairly basic and one upper level learning standard, the latter only if necessary. Since the water air-lock is based on the properties of pressure, acceleration due to gravity, vertical height, and density, the learning standard of defining and explaining density was used to include it.

This standard was also a great way to further reinforce the major concept of acceleration due to gravity which played a role in both of the other activates. However, there was a need for an interesting and interactive, "hands-on," activity. This activity was derived from the scientific instrument used to perform calculations and tests using Bernoulli's Principle and similar such principles, the U-Tube Manometer. The activity would feature a U-Tube manometer attached to a pressurized air tank, with controllable pressure, on one end and exposed to atmospheric pressure on the other. Via manipulation of the tank pressure, students would be able to make the water level rise and fall, the height of which could be used to prove the principle or could be compared to calculations using the principle. This activity would also allow students to compete against each other to bring the water in the manometer to certain heights, demonstrating reinforcing the concepts they learned and demonstrating their grasp of the learning standards that the activity needed to meet.

Initially, the air-lock was also going to be used to explain the "conservation of mass in a closed system." This was another learning standard, based on and reinforcing the concept/definition of density. Due to time constraints and the simplicity of the other activity's concepts coupled with the difficulty of this particular standard, it was deemed necessary to reserve this "auxiliary" standard as something for the higher grade levels in the proposed span assuming they were already familiar with/had been exposed to the easier concepts. Once all of this was taken care of the design and logistics of the activity were created and set into stone with the unique idea that the two "lunar surface" activities could flow nicely into the water air-lock or vice versa, especially since all the learning standards were interconnected.

In designing the entire exhibit it was also made apparent that the mock "lunar surface could be used for activities from other exhibits, and if necessary the touch screen computers available in the water air lock could also be used for other exhibit's activities, based on need and the amount of students on each field-trip to the Lunar Base Exhibit. At this point in time, the Moonwalk Exhibit is extremely close to reaching completion. After being tweaked and numerous times with the current activities in mind, it emerged better and more developed than before. Further additions need to be made in the addition of graphics to convey how the water air-lock will look like when installed on the moon and attached to the lunar base. This will be done, most likely, via a two dimensional "cross section" graphic, depicting the lunar surface, the water air-lock, and its connection to the subterranean lunar base.

The full Moon Walk exhibit with in depth descriptions of everything as well as graphics can be found in the Narrative Appendix under "Full Exhibit Proposals". The learning standards featured in the exhibit are also quoted in the full exhibit proposal. These quotations, including page numbers from the STEM Curriculum, can be cross-referenced with the condensed version of the Massachusetts STEM Curriculum featured in the narrative appendix under, "Massachusetts STEM Curriculum Framework (Project Specific)." The paraphrased standards for the Moon Walk Exhibit as they currently stand are as follows: differentiate between weight and mass as well as the effect of gravitational pull on weight, compare and contrast properties and/or conditions of object on the moon and on earth, define density while differentiating between its properties, and explain how mass is conserved in a closed system. There process of researching whether there are any other standards pertinent to the exhibit without change is nearing its completion. This exhibit is complete with a detailed three dimensional visual that represents its proposed design.

Lunar Greenhouse Exhibit

The original concept for the Lunar Greenhouse Exhibit was for it to be a large, fully-equipped greenhouse full of plant life with working water and carbon dioxide recycling systems. It was supposed to be designed to look like it was part of an actual lunar base to give the students the feeling that they are actually on the moon. They would have been able to touch, smell, and even eat the plants growing in the lunar greenhouse. The plants were going to be ones that do not need natural sunlight to grow, due to the fact that the exhibit would be in the basement of the Worcester Memorial Auditorium. An actual lunar base also would not have any windows or skylights because the entire thing would need to have appropriate shielding from radiation, solar flares, meteors, and other dangers. If there were windows, the glass would have to be so thick that basically no light would get through it. There would have been lights inside the greenhouse to provide the plants with light energy, powered by solar energy collected from solar panels somewhere on the surface of the base. The greenhouse was also supposed to include explanations of how water is recycled throughout the lunar base and how the carbon dioxide used by the plants would be filtered from the air that the astronauts breathe. The students would have learned about how water could be recycled and reused in a place where there is no atmosphere for the water cycle to exist, how certain gases can be filtered from the air, and about photosynthesis. They also would have learned which types of plants provide the necessary nutrients for the astronauts as well as provide building materials and which ones would grow best on the Moon. As the group began to further discuss the concepts of lunar living, the greenhouse exhibit was expanded to also include concepts of biology. The students would also learn about the nutrition/medicines that a real astronaut would need to survive in a lunar environment and how the Moon's gravity affects the human body.

As a group, it was decided that all of the exhibits and activities should be based on the Massachusetts Science and Technology/Engineering Curriculum Framework since it lists are the STEM concepts and standards currently being used in all schools in Massachusetts. After looking through the science topics for grades six through eight in the Framework, it was realized that there is only one standard that is usable for the greenhouse exhibit: one on photosynthesis from the Life Science and Biology portion. At this time, the group had also decided that there should be five individual exhibits within the Lunar Base Exhibit and that the entire trip should only take about three to four hours, giving the students and their chaperones enough time to get to and from the exhibit during a typical school day. This limited each individual exhibit/activity within the trip to about thirty minutes. It was also decided that the maximum number of students should be one hundred fifty plus their chaperones, with a group of about thirty students visiting an individual exhibit at one time.

Based on these requirements, a complete greenhouse would not be necessary. To help make the Lunar Base as educationally valuable as possible, the concepts explained in the greenhouse should reflect only topics from the Framework standards, which means that the only concept needed is photosynthesis. From that point, the greenhouse exhibit was changed completely to include one activity that will fully explain photosynthesis in a fun way. The students, working under adult supervision, would perform an experiment to determine which part(s) of the plant leaf indicate(s) the presence of starch, a product of photosynthesis. The idea for this type of experiment came directly from a suggested activity corresponding to the photosynthesis learning standard in the Framework: "*Test for sugars and starch in plant leaves.*" (pg. 53). Each student would test the leaves of two green plants, one kept in darkness and one kept in light for twenty-four hours, and determine which plant had photosynthesized and which did not. The concept of the experiment is for the students to learn that light energy plays a key role in plant photosynthesis and growth. It is also the reason that they are able to thrive on the Moon the same way they do on Earth. All the plants need is an environment that provides them with everything they need. Students will also learn that photosynthesis is performed in the chloroplast, which is also responsible for giving them their green color. They will make the connection that photosynthesis occurs in green parts of plants that have received light energy, which is where the starch will be present during the experiment.

The design of the Lunar Greenhouse, to include this new activity, had to be changed quite a bit from what it was to be originally. Instead of the greenhouse being full of lush, green plants, it will be more of a simulated greenhouse and have plant "props" and/or videos and images showing the interior of actual greenhouses. The videos and images can possibly be taken from Tower Hill Botanic Garden in Boylston. The "plants" and images/videos will be mostly along the walls of the greenhouse and in the middle will be six large round lab tables with chairs. Each lab table will have five or six chairs to accommodate the thirty students in the exhibit and their adult supervisors. The greenhouse exhibit will attract the students because it will look mostly like a science lab with all the lab equipment set up on the tables for them to use. The students will get to wear safety goggles, gloves, and lab aprons and feel like a scientist for half an hour, using beakers, chemicals, and tools. For most of the students, this would be their first time in a lab environment. Performing this experiment would also help prepare them for high school and college chemistry labs because they would learn that they have to follow a procedure precisely in order to get the expected results for the experiment. They would also learn that sometimes the results of an experiment are not what they expected and they have to think of what may have caused this.

Mission Control Exhibit

The Mission Control Exhibit was more of a group effort than the rest of the exhibits. It was originally decided that whatever did not fit into the Moon Walk, Lunar Greenhouse, Lunar Expedition, or Regolith exhibits would be used in the this exhibit. From the beginning, it was planned to be a very interactive exhibit with computers and programs that the students would use to learn different concepts. Its design would closely resemble an actual mission control room, basically a large room with rows of computers and a large screen up front. The room would have about forty computers to be used by the students and their teachers. Each student can have their own computer to work on or they can work in teams of two based upon the grade level. The room will have a large projection screen up front accompanied by a ceiling mounted projector and a computer station to work it all. It was decided during the second term of working on this project that the computers would be used to view educational, but fun and interactive, videos and games that explain four science and technology topics: radiation, the phases and movement of the Moon, communications technology, and transport technology.

The first topic, radiation, is part of a standard in the Earth Science for grades sixth through eighth grade MA Curriculum Framework. It is very important to explain because it is the most common form of heat transfer that occurs on the Moon, due to the Moon having virtually no atmosphere to shield its surface from the sun's heat. Exposure to too much radiation can also be very harmful to humans. The process of heat transfer by radiation will be explained through interactive videos. The videos will deal with the topic in varying levels of depth based on need and touch upon it as a potential danger of a moon base. Once the concepts of radiation and its dangers are explained, the concepts of shielding and protection can also be explained via educational video based on the group of students' level of education and previous exposure the subject. Topics can include water as a source of shielding, how much regolith would be needed for shielding, how the moon base would need to be built in a crater and mostly underground, and creative design ideas for moon base to protect against radiation, etc.

The second topic for the Mission Control Exhibit explains the phases of the Moon and its movement. One problem that the group ran into while discussing this topic was whether or not it is factual to say that the Moon does not rotate because the same side of it is always facing Earth. Through some research, a group member concluded that the Moon does in fact rotate with a velocity relative to its orbital velocity, which is why it appears as though it is not rotating. In other words, the Moon completes one rotation in the same amount of time as it completes one orbit of the Earth. For this topic, there will be educational videos that explain how the moon's movement impacts communication between astronauts on its surface and on Earth. The videos would rely on interactive graphic depictions of how communication signals would travel between the moon and earth and what conditions would prevent communication and at what times. Videos could, based on need and/or education level, touch on the effects of the moon’s orientation in regards to the sun and how the location of an actual base on the moon would be chosen based on the moon's phases and movement.

Some of these videos would also tie into the third topic of communications technology. The students will be able to compare/contrast visual and audio communications using videos explaining the differences, the need for one or the other, how they are both used on the Moon between different parts of the base and outside of the base, and how they are used for communication between the Earth and the Moon. The concept of receivers and transmitters will be shown via an explanatory video. There will also be a fun game dealing with the phases and movement of the moon and communication technology together. The game will most likely involve sending signals or messages to other students in the mission control room, or even to other students back at their school as if those students are on Earth while these students are on the Moon. The game will probably include subjects such as basic math, algebra, or pre-algebra, based on grade level.

The fourth topic for this exhibit is transport technology. This activity would include videos and/or games that would explain the many forces that act on a space shuttle when it is taking off and landing and when it is in space. These forces include weight, lift, drag, and thrust. The videos and educational games will involve math and basic physics concepts. The video will touch upon the differences between acceleration due to gravity (g), drag force, lift force vs thrust, and the impact that different g and atmospheres (or lack thereof) have on these forces. The videos/games will also introduce the equation of Newton's Second Law W=mg (weight = mass x acceleration due to gravity).

These four concepts were chosen to be included in the Mission Control Exhibit activities because they are all within the standards of the MA Curriculum Framework. The group wants the students to learn about things that actual astronauts have to deal with when in mission control rooms on Earth and in space. Obviously, communications is a huge part of mission control, but astronauts also have to be very knowledgeable in space travel and how a space shuttle gets from point A to point B. They also must know the Moon's movements so that they can predict communication paths and plan them accordingly.

Regolith Exhibit

The regolith exhibit evolved out of a need to create something to cover some chemistry, technology, and engineering learning standards all while keeping to the moon base theme of the exhibit. The initial exhibit ideas that came before this concept did not particularly have anything to do with it. The main exhibit idea before the creation and finalization of the regolith exhibit was an exhibit on habitation/space living. This did not present a particular problem in terms of research, but it also touched upon concepts such as air quality, human necessities, and waste. These overlapped too much with the proposed greenhouse exhibit at that time, which also dealt with air, food, and waste. The decision to focus on living quarters, habitation, and entertainment, solved the overlap issue but a bigger problem would eventually present itself.

The problem with the lunar living/habitation exhibit was the fact that it could not be related to the learning standards in the curriculum framework. This became an apparent issue after the overlap problem was solved. Based on the fact that the group desperately needed to stick very closely to the curriculum framework, the idea of the lunar living/habitation exhibit was scrapped.

A new exhibit concept was created to fit standards that were not already taken, focusing on portions of the curriculum not covered by the other exhibits. Thus the regolith exhibit was born to coincide with the major lunar surface and regolith theme that had sprung up in two of the other exhibits. At first, the regolith exhibit involved an activity that related to sifting the ersatz regolith, composed of different colored balls of different sizes, through a tool with different sized holes. While this was a good start, the group agreed that it needed tweaking to make it better.

The concept was eventually changed to where the students design a tool using a very simple magnetic peg board. This tool sorts the balls based on their sizes into containers below the pegs. The goal of the activity is to create a tool using the peg board that will sort the balls so that like colors are in the same container. This would stress the fact that regolith is not a pure substance but a mixture of different elements and compounds. It would also show the need for appropriate and specialized tools in science and engineering while giving students a bit of insight into what it takes to prototype and design a tool.

The exhibit would begin with the students being asked to sort the regolith by hand. While this is an exaggeration as it cannot be sorted by hand, there exist mixtures that can be. The use of the hand separation is to spark the question of whether there exists an easier method of sorting than by hand. This method would most likely involve a tool. The question of, "what kind of tool," then becomes pertinent. To separate the regolith more efficiently a specialized tool would be needed. The students then learn that in order for a specialized tool to exist, one must be prototyped and designed. They are then given the task of creating a specialized tool that would correctly and efficiently sort the regolith in an easier and more pleasant manner then having to do it by hand. They are also exposed to the fact that the regolith can be "sorted" (separated) because it is a mixture. If it were a pure substance, they would not be able to separate it into different components, as a pure substance is made up of only one component.

The exhibit was then tweaked to further stimulate the students' interest by making it into a contest. The group would be divided into 5 or 6 groups of equal size which would have a limited amount of time to create and test their sorting tool. After the time was up, each group would use their tool to sort some regolith and see which group's tool was the most effective or had the best design.

This exhibit would expose the students to the learning standards of: differentiating between mixtures and pure substances, identifying and explaining the engineering design process, describing and explaining the purpose of a prototype, and explaining how design features can affect the construction of a prototype. To allow for cross-referencing, a copy of the pertinent curriculum framework for this project is included in the Appendices. It would do all of this while exposing them to the concept of regolith in a tangible and easy to understand way. Each ball would stand for a different element or compound that regolith was composed of, allowing the students to decompose it and learn about its composition.

The exhibit's proposal is located in the Appendices complete with a three dimensional graphic. The logistics of this exhibit are set and agreed upon, with an outline and thorough description located in the proposal (see Appendix).

Robots Exhibit

From the very beginning, the team had planned to do something, most likely an exhibit, with Robots. However, this concept took a while to narrow down and polish. This is mainly because before B-term, there was not as much focus on the curriculum framework as there was in the final completion stages. Until then the exhibit did not really take shape besides for the research. An overview of Robots in Lunar Expedition is included in the Appendices. However, the team met to discuss the exhibit and how it should relate to the curriculum and to which standards. This happened toward the end of B-term and after the need to strictly follow the curriculum became extremely clear, partially due to the Brian Moriarty's discourse A-Term and partially due to the problems that not following the curriculum cause in relating the potential exhibits to the learning standards. After discussion, the team came up with the learning standards that are currently being used for this exhibit, and the exhibit was essentially built around the standards all while incorporating robots and the lunar base concept in a fun, interesting, and educational way. Initially this exhibit was created to take anywhere from an hour to an hour and twenty minutes. This was not part of the original plan for the lunar base exhibit as all of the exhibits it contained were supposed to last no more than half an hour. The team discussed this and agreed to extend the length of the entire lunar base exhibit in order for this exhibit to maintain its original length. This is because of the merit of this exhibit in terms of attracting students and educations, and its ability to excite and interest students with its futuristic concept and its accessible nature.

The Massachusetts curriculum will be used as a guide line for the robotics exhibit throughout the fifth to eighth grades; focusing on manufacturing technologies and transport technology. It states “4. Manufacturing Technologies, Central Concept: Manufacturing is the process of converting raw materials (primary process) into physical goods (secondary process), involving multiple industrial processes (e.g., assembly, multiple stages of production, quality control). 4.1 Describe and explain the manufacturing systems of custom and mass production. 4.2 Explain and give examples of the impacts of interchangeable parts, components of mass-produced products, and the use of automation, e.g., robotics. 4.3 Describe a manufacturing organization, e.g., corporate structure, research and development, production, marketing, quality control, distribution. 4.4 Explain basic processes in manufacturing systems, e.g., cutting, shaping, assembling, joining, finishing, quality control, and safety. . Transportation Technologies Central Concept: Transportation technologies are systems and devices that move goods and people from one place to another across or through land, air, water, or space. 6.1 Identify and compare examples of transportation systems and devices that operate on or in each of the following: land, air, water, and space. (6.1) 6.2 Given a transportation problem, explain a possible solution using the universal systems model. 6.3 Identify and describe three subsystems of a transportation vehicle or device, i.e., structural, propulsion, guidance, suspension, control, and support." The exhibit goal is to get kids to be creative enough to build and program a lunar robot to go over the terrain to collect different color balls (which will represent regolith). The exhibit will be split into two parts, first part is to build the robot and the second will be to program the robot, along with testing it. The maximum amount of kids will be roughly 24.

The exhibit will be set up with building stations that contain Mindstorm Ev3 Kits on tables roughly 3'x3' about 2' high with a distance of 3.5' from each other. The computer station will be composed of 6 computers on each side for each team. Testing stations will be composed of 2 tables 3.25'x6.67' put together so teams can race when programming is done.

Kits will be provided using Mindstorm kits. The core set contains 400+ Lego elements including the EV3 brick, 2 large motors, 1 medium motor, an ultrasonic sensor, a pair of touch sensors, a gyro sensor and a color sensor. The expansion set, which could be bought separately, contains 600+ Lego elements.

The programming for the kits is fairly easy to use. The software runs off of pictures that kids can drag and drop to their desire place along with tell the robot to view certain colors, how far away something is, and much more. An example of how to use the program is: http://www.youtube.com/watch?v=m-XcGt8CsWc. Here is an example of a robot with color sorting capabilities: Basic programming: http://www.youtube.com/watch?v=m-XcGt8CsWc

The terrain will rest on the tables as mentioned before. In one of the outside corners kids will place their robot. As the kids go along the board, the surface changes from a slick surface, to represent the icy surface, to a powdery floor, to show loose rock. Closer to the end of board, it will slightly angle upward and then back down to represent a crater.

The first activity will consist of the students teaming up in groups of 4. It will take up to forty minutes to build a robot to take on the terrain. Ten minutes will be used to look at the terrain for teams to come up with ideas on how the robots may look like. Example robots will be provided through pictures.

The second activity will consist of teams programing the robot to scout out different color balls throughout the rest of board. As the teams go further up the board, the difficulty of the board gets harder.

The exhibits relate to the Massachusetts curriculum because with manufacturing technology, kids will demonstrate custom manufacturing systems by working in teams to show creativity and how interchangeable parts/robotics work. Kids will learn about transportation technology as a result of the robots transporting regolith. This will be aided by the fact that the kids will be able to see the differences between the robot they create and the robots that other teams create. They will also see how guidance and control work from programming the robot.

The logistics and the design of this exhibit are laid out in depth in the exhibit proposal (see Appendix). This exhibit is complete with a full three dimensional designs.

Exhibit Expansion, Modification, and Finalization

Lunar Greenhouse Expansion

The greenhouse underwent numerous changes and additions in order to broaden its scope and expand its lesson on photosynthesis. When the greenhouse exhibit was originally designed, it was given as much importance and emphasis as any other portion of the base. However, a case was made to emphasize the greenhouse by increasing the physical room size of the greenhouse sub-exhibit. The reasoning behind the increase in greenhouse exhibit size was to make the simulation more realistic. The 2069 lunar base would have the majority of its usable space taken up by a greenhouse. However the size of the greenhouse exhibit was never expanded since it was eventually decided that our exhibit would only take up half of the usable space in the Worcester Memorial Auditorium Basement. This decision was made to make space for a sister exhibit involving a Mars base. Instead emphasis was placed on the greenhouse by expanding its educational content and including C3 and C4 photosynthesis plants. The educational experiment performed inside the greenhouse remained unchanged, the greenhouse exhibit was expanded in terms of the plant life that it covered. The major change made to the environment was the inclusion of both C3 and C4 photosynthesis plants. There are three types of photosynthesis: C3, C4, and CAM. Of the three, it was important for the contest to include both types of plants as it added to the realism since a lunar base greenhouse would without doubt house both types. Both C3 and C4 plants can be kept in standard atmospheric conditions but C3 plants thrive in carbon-dioxide rich environments. This change does not allow us to touch upon any more STEM curriculum learning standards, it does however allow for supplementary lectures on the different types of photosynthesis with a possible option for a lecture on evolution in comparing the C3 and C4 plants.

This modification also influenced the exhibit design so it would fall in line with the carbon-dioxide rich environment. The exhibit was designed C3 plants are kept in an area enclosed by safety glass and exposed to double the normal level of atmospheric carbon-dioxide. The C4 plants are kept at normal atmospheric conditions and distributed around the open portion of the exhibit area.

It terms of exhibit design, once the concept of the exhibit was set in stone, the graphic design began. At first, it was not clear how the design was to take place. It was decided that we could create three-dimensional designs to represent each exhibit. After some consideration, we decided upon Google's SketchUp software as our design software. This was because of its ease of use and its "free" version. It was also useful in that it had an "architectural" design feature which allowed 3D designs to be created in scale using feet and inches.

Design started with calculating the rough size of each exhibit and creating the "room" in which the exhibit would be housed. The greenhouse was housed in a fairly square room. The overall "look" of the environment was futuristic with industrial architecture to accentuate the futuristic feel. The majority of the props, furniture, and items in the exhibit were made of metal. The greenhouse exhibit was filled with plants and one of the walls would be a full wall sheet of safety glass behind which the high carbon-dioxide enclosure would be located. One or more of the other walls could also feature projections or screens which simulated more greenhouse space or were images from another greenhouse.

Lab tables and chairs were included to give the students a place to complete the greenhouse lab experiment.   A smart board and computer work station were also included for the benefit of the educators and staff. To add to the visual appeal, the room was filled with lush green plants and a large patch of corn positioned in the center of the room.

The greenhouse is connected to both the Mission Control and the Regolith exhibits and is roughly 3600 square feet in size with room dimensions that are very close to 60 square feet by sixty square feet. The area is more than enough to fit the exhibit as well as a maximum of 30 students with teachers, chaperones, and any necessary educational staff.

Moonwalk Finalization

The Moonwalk sub-exhibit, also known as the Lunar Surface, is comprised of two environments and therefore two rooms. The lunar surface was finalized with no modifications to content or scope. The water air-lock received some minor modifications, but nothing was drastically changed or added. The activity and the educational concept remained the same for the water air-lock, but the number of manometers was altered. The exhibit was revamped to accommodate roughly thirty students working in groups of three with two manometers to a group. Each lab station was set up with two manometers for a total of ten stations and twenty manometers.

The change in grouping structure and the number of manometers was to facilitate a competition after the manometer activity. Once the students have completed the activity in which they learn to operate manometer through the use of air tank pressure, they will compete against each other to see which team can operate their manometers most efficiently. Each team will operate two manometers simultaneously to achieve certain pressure differentials via the change in height of the fluid in the manometers. The team to that operates the manometers with the best combination of speed, accuracy, and precision will be the winners. There are multiple methods that the students can use to try to win as they are provided with the equation that the manometer follows an explanation of the physics concept that is behind the manometer’s function. The students also receive a chance to practice working the air tank and manometer in order to gain a sense of intuition as to the effects of a change in tank pressure.

The lunar surface exhibit was created with realism in mind, but there were a number of compromises that had to be made in order to strike a balance between realism and practicality. Regolith, lunar soil, has a consistency which makes it extremely impractical to the point where it can become a potential hazard. Regolith resembles a very fine dust and having any sort of similar material in the exhibit would be extremely problematic. Even having a sand-like material that resembles regolith only in color would be problematic. It was decided that the floor of the lunar surface should be a hard rubber that resembles the surface of the moon in general topography and color. The lunar surface will also have a portion of it reserved for a trampoline surface. The walls of the exhibit will be big screens with lunar landscapes projected on them. The surface has two raised areas opposite from each other. One holds the objects that weigh as much as they do on earth, and the other holds the objects that weigh as much as they would on the moon. The lunar surface's major design modification was the addition of two "regolith pits". The regolith pits are shallow, less than 4 feet in depth, pits filled with the exhibits "regolith," an amalgam of different wax balls that vary in color and size. This is to make more "regolith" available and to create an auxiliary environment that the regolith and robots exhibits can use if they require extra space or more "regolith."

The water air-lock is a more intricate design and underwent a significant amount of modifications before it was finalized. The water air-lock is a unique environment in the lunar base exhibit as it is designed to give students the sensation that they are in a room that is completely submerged in water. This was done by surround the entire room wall to wall with floor to ceiling water tanks made of safety glass. The tanks are not thick, but they line all four walls and are filled with water. Behind them could be any sort of subterranean view of the moon or screens to allow for the background image to change. The manometers are complete with lab stations that have pressure tanks and all of the equipment necessary to complete the manometer activity. The manometer lab stations line the walls while two big computer workstations with multiple computers and auxiliary screens are positioned in the center of the room. In the corner of the room, surrounded by three walls, is the airlock hatch. It is raised above floor-level and is filled with water. While it is only there for simulation, it is the hatch that astronauts would use to exit and enter the base. Next to the hatch are some benches and a large cabinet that houses the spacesuits. For the purpose of realism, the cabinet would be filled with several spacesuits, although they would be replicas. The design of the environment would be very industrial with very few, if any, organic materials. The majority of the items in the environment including the floor would be made of metal. It was decided that one of the walls, at the very least, will have a screen behind it in order to help simulate and actual water-air lock. The screen will show base personnel moving vertically in both directions as they take the water air-lock up to the surface of the moon and back down into the lunar base.

Mission Control Expansion and Finalization

The mission control was transformed into an innovative and all-encompassing exhibit as a result of the lunar base exhibit contest. One of the two main sub-exhibits stressed by the contest was the mission control. While we included it as part of our lunar base exhibit, the design was initially lacking innovation. The learning activities that were proposed for mission control involved educational videos and games. Unlike the other sub-exhibits, the mission control is used to cover more than one STEM curriculum standard. The mission control’s flexibility allowed us to cover the standards that we viewed as important, but could not include in any other exhibit. The problem with the flexibility was that it became a little more unstructured than it should have. While individual learning has its place, we eventually decided that it was important for any group visiting the mission control to be doing the same activity.

To solve this problem, it was decided that the mission control would continue to focus on more than one concept but each group of students that visited would only be exposed to one of the concepts. The deciding factors behind which concept would be presented include grade level, previous exposure/knowledge, and any particular interest the students or their teacher had in one of the proposed topics. This added an element of structure that was previously missing from the exhibit.

The exhibit was becoming more and more developed as a result of the contest, but it was still missing something. The educational videos and games had their place in the exhibit, but they weren't innovative and resembled something you might find in any other sort of educational exhibit. The team wanted something more that would attract the students as well as challenge them to put whichever concept they had learned about to the test. It was decided that there should be a group activity to encourage teamwork as that is one of the key concepts that any sort of "mission control" is based on.

Rather than playing interactive games as individuals or in small groups, we decided that the students should play and education game as a whole class, a mission control team. This game would take the place of the individual games and have a very intense focus on teamwork. The game would remain an interactive one but it would resemble a simulation rather than a mundane computer game. The idea of what this game should be took some time to cultivate, but we eventually created a game that fit not only the sub-exhibit, but the scope of our entire lunar base exhibit as it was designed to be a flexible, team-based, simulation that could be used for any of the concepts that we chose to present in the mission control.

The interactive game involves the students manning mission control stations which each have at least one big screen visible to them. These screens present pertinent information to the students in addition to what is presented at their computer control stations. Regardless of the topic presented in the exhibit, the students must keep the systems that they are given control of in working order. This is very similar to a real mission control except that the simulation will always feature one or more problems for the students to resolve. The solution of these problems is based on teamwork and fast, educated, decision making. The problem will only appear on one of the status screens and it is the job of whoever is viewing the screen to alert the rest of mission control. Mission control can only remedy the problem as a team, which means that everyone must be notified of the problem. The longer it takes the students to react, the more complex the problem becomes and the more difficult it is to solve. The students can win the game as a team through communication, teamwork, and educated decision making or they can lose as a team if they take too long, hesitate, or if there is a breakdown in communication.

The graphic design of the exhibit drew its inspiration from the revised activity that gave the mission control its appeal and simulated sense of being on a lunar base. At first, the exhibit was modeled after a “Hollywood” mission control that one might see in any science fiction space movie. The mission control has one big projection screen up front and rows of long tables with computers from front to back. This did not lend itself to the redesigned activity so it was decided that it should be modified in favor of something more creative and conducive to communication and teamwork. The concept of a “round table” approach to mission control was introduced and it inspired not only the layout of the control stations, but of the status screens, and of the entire room. The mission control room is unique in the fact that it is a circular room. The entire outer circumference of the room is lined with screens so that information or images may be displayed on the outer wall if necessary. The control stations are arranged in a big torus (donut shape) with the students and the computers facing inwards, toward the center of the circle. Inside the torus of workstations is another torus comprised of status screens. They are positioned facing outwards so that they can be seen by the students sitting at the control stations. The concept of a round control station bank was used because a round table facilitates communication, which was a big theme for mission control. A square workstation with computers for educators and staff was also added into the center of the torus for make it easier for them to facilitate the learning and present the exhibit and its educational videos and lectures.

Regolith Exhibit Expansion and Finalization

The final round of critiquing, expanding, and improving upon the regolith exhibit yielded one major upgrade, materials processing. The need to incorporate this comes from the fact that the regolith could not just be sorted into different elements and utilized without going through this vital process. To illustrate this new procedure, the “balls” that make up the regolith substitute would be made of paraffin wax. After separating the regolith with the peg board, each student would have the opportunity to then “process” the regolith. This is achieved by melting the ball, pouring it into a mold and submerging it in cold water to cause it to harden. The thought progression behind this is that heating is used as a way to separate materials, while also being simple enough so that it is easily understood by middle school students. The decision to use paraffin wax is for the safety of the students. The wax has a low melting point and would not burn the students, meaning they would be able to manipulate it under a chaperone/teacher’s guidance, as opposed to watching it be done for them. By allowing the students to use a hands-on approach the hope is that they will take more care and focus more on the exhibit. Using molds for the wax and allowing children to keep the item that they made reinforces that belief and serves as a reminder to what they have learned at the exhibit as a whole in the future whenever it is handled by the student.

Robots Exhibit Finalization

The robotics exhibits went through a few changes in terms of information presented and educational concepts. The layout of the exhibit, however, remained largely the same from beginning to end.

The goal of the exhibit is to look as futuristic and realistic as possible. The original look had a classroom “feel” to it. It used wooden tables, basic looking computers, and simple Lego kits. In order give the exhibit a more futuristic “feel”, the table material was changed to black sheet metal. The computers were updated with modern computers and flat screen monitors. The Lego kits will also be continuously updated to the latest editions. Along with the aforementioned changes, the room will be filled with robots that the students can interact with. The walls will also be made to resemble the surface of the moon, craters and all.

Conclusions and Recommendations

Looking back on the project there are a few areas that we could have improved upon that would have made the project run much smoother. The biggest conclusion we drew was to start working with the curriculum from the very start. Working with the curriculum sooner rather than later would have given a better idea of what to focus on while designing the exhibits. Originally the thought was to design a series of moon base related exhibits and then incorporate them directly into the exhibits. After looking more in depth into the curriculum, we learned that the thoughts and exhibits we had designed would not be able to sufficiently cover the learning standards.

This also leads to another conclusion we drew. Picking a key educational concept and then designing the exhibit around that concept is a much more efficient process to creating the exhibits. The complexity of a lunar base leads itself to being able to easily find a way to incorporate an educational topic into an exhibit centered on a lunar base. For example, an obvious possible exhibit choice would be on lunar living. However, the curriculum does not provide many possible ways to incorporate learning standards into that exhibit. Related to this topic however, is the food that anyone stationed on the base would need to eat. A key concept in the curriculum is photosynthesis and plant life. This is much easier to incorporate into an educational exhibit under the topic of a lunar greenhouse.

This project was titled as a “Lunar Base Exhibit Contest Entry”. While this left little room for confusion, it also implied a heavy dependence upon the “Lunar Base Exhibit Contest”. The problem with this heavy dependence is that while a contest of the same title had existed in previous years, a new contest was in its early stages of development. The lack of “set in stone” contest coupled with the creation of a contest that would be radically different in its objectives and scope proved to be a significant hindrance. This created the initial difficulty for this project in that it had no guidelines or direction to follow. This project essentially required double the work. Half of the work on this project was setting the guidelines by which it would be completed. A lot of time was used inefficiently in search of an acceptable direction to take the project in. Very little design was initially done because without direction the only way forward, albeit via slow progression, was through research and the review of pertinent literature.

What little guidance the project received was in the form of guest speakers/lecturers on various topics related, some more some less, to the concepts of a lunar base, a lunar base exhibit, and the education of our target range of students. These speakers proved to be useful as we incorporated their advice and ideas into our project. The speakers would have proved much more useful, however, if we had met with them much earlier in the project. They would have provided us with inspiration and direction early on allowing us to make better use of our time.

If the team had a chance to take on the project anew, we would have included the McAuliffe Center of Framingham State University as inspiration for our project. Ideally we would have visited the center early in beginning of the first third of the project. We did not have a chance to visit the McAuliffe Center until it was only brought to our attention late in the project. Regrettably by that point exhibit design was already heavily underway and there was no spare time to devote to a visit. The McAuliffe center's mission is very similar with the mission of the lunar base exhibit and it would have been an excellent source of inspiration, guidance, and background information.

It was concluded that a significant amount of the problems encountered in this project came about as a result of a lack of guidelines. Had we been more decisive, with a stronger direction to follow, a lot of time could have been used much more efficiently yielding a project of greater depth and breadth. However, we were able to overcome these setbacks with a combination of creativity and innovation that allowed us to set the guidelines and make this project our own. While our vision was not perfect, we continuously worked to improve it, exploring numerous possibilities until we settled on what would be our final concept.

In the future this project might benefit from a stronger set of guidelines to follow. It might also benefit creatively if the team was given a little more "free reign" as we found it necessary to tie our project very closely to the Massachusetts STEM Curriculum. This would allow future students to take the project in their own unique directions and develop forward-thinking sub-exhibits that are not as constrained by the need to follow the curriculum so closely.

Project Narrative Appendices

Full Exhibit Proposals

Moon Walk Exhibit Proposal

Proposed Number of Students for Exhibit: Max 30 + Educators/Chaperones
Proposed Time Spend in Exhibit: 30 Minutes
Proposed Space for Exhibit: Maximum of 5000 ft^2

Water Air Lock: ~ 2000 ft^2 (imitation of a room submerged in water)

Description: The water airlock would be modeled in an industrial style after what an elevator on the moon would look like. Every empty portion of wall space would have thin water tanks that span the entirety of the wall. These tanks would be filled with water and have an earthy background/backdrop to simulate being underground. The room would have up to thirty stations complete with their own touch sensitive computers. Each station would also have a U-Tube Manometer Similar to the one depicted in Image 3 of the proposal appendix. One end of the manometer would be attached to an air tank similar to the one depicted in Image 4 of the appendix. The tank would be fitted with an analogue pressure gauge and a simple air release knife valve (used to decrease tank pressure) also depicted in Image 4. It would also be connected to a source of compressed air (pump, compressor, etc.) in order to increase tank pressure. The room would also feature a projector and work station for it. All manometer work stations would be metallic and constructed with a futuristic industrial moon "look" in mind. The same can be said for seating and other portions of the room.

Lunar surface: ~ 2000 ft^2 (rough simulation of surface of moon)

Description: The moon surface would be created to portray a realistic looking moon surface. It would be barren, rocky, and covered with a fake equivalent to lunar soil. The walls would portray a lunar landscape via moving lunar landscape video portrayal that would be projected on the walls using the projectors fitted in the room of which there is one for each wall. The ceiling would mimic a starry night in space. There would be a portion of the surface that was springy/bouncy/a trampoline. It would be just enough to recreate a feeling of lesser gravity/allow someone to jump slightly higher, while still being safe and not allowing someone to make contact with the exhibits ceiling. The rest of the exhibit would be open in order to allow the throwing of various sports balls for one of the exhibit activities. The lunar landscape would also feature “regolith pits”. These pits would be filled with wax balls of various colors and sizes. These balls are used in the Regolith and Robots exhibits. They represent the various elements that regolith is composed of based on their colors.

1. Students arrive on surface of the moon
    - First Activity is using objects that look similar but are weighted differently in order to simulate the difference between the weight of an object on earth and on the moon (10 Min). The majority of these objects would be sports balls in pairs. Each one would look identical but one would be weighted to six times its normal weight. This would allow the students to simulate the difference between the weight of an object on the moon and on earth. The students would be given a preface about the difference

between properties of the moon and earth. This would rest upon the fact that the acceleration due to gravity on earth is roughly 6 times larger than that one the moon. This means that objects on the moon are six times lighter than on earth. The students would be able to pick up/lightly toss the balls to feel the difference fist hand. They would also be exposed to varying degrees of math in order to calculate the difference in weight of an object between the moon and the earth via the projector.

  - P. 33 Standard 10 for Gr 6-8 {Compare and contrast properties and conditions of objects in the solar system (i.e., sun, planets, and moons) to those on Earth (i.e., gravitational force, distance from the sun, speed, movement, temperature, and atmospheric conditions).}

- Second Activity is a moon bounce using a spring/bouncing surface or a harness (ropes, counterweights, etc.) in order to simulate the feeling of reduced weight on the moon. This is to explain the difference between weight and mass. The projectors would be used to introduce the concepts of weight and mass, manipulate the equation that correlates weight, mass, and gravitational acceleration, and show examples of the equation being used to calculate the mass and weight (on moon) of a few of the students. The students would then have the change to bounce around on the "lunar surface" in order to feel what it would be like to jump up and down on the moon under reduced gravity. The difference between mass and weight would be stressed: weight changes based on gravitational acceleration but mass is a constant. (10 min)

Weight = mass X acceleration due to gravity

- P. 67 Standard 1 for Gr 6-8 {Differentiate between weight and mass, recognizing that weight is the amount of gravitational pull on an object.}

2. Students Enter "Water Air Lock" to get down to the base (15-20 minutes)

Explained by Bernoulli's Incompressible Flow Equation

$$\frac{v^2}{2} + gz + \frac{p}{\rho} = \text{constant}$$

Since this is a static problem, fluid velocity $v = 0$ it reduces to g*z+ (p/rho) = constant

Use this to define Density and Differentiate between volume and mass as per:

P 67. Standard 2 Gr 6-8 {Differentiate between volume and mass. Define density.}

Rho=mass/volume

Also explain how mass is conserved in a closed system

P 67. Standard 4 Gr 6-8 {Explain and give examples of how mass is conserved in a closed system.} **Advanced topic that will be touched upon if necessary*****

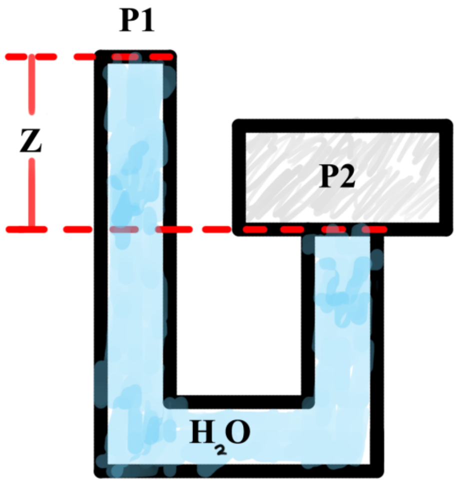
There is a difference in pressure. G is the same. The system is ideally closed so mass is conserved. Since the volume of water remains constant one can say that density is also conserved. For the equation to equal a constant between a pressure difference the Z (Vertical height must change).

ACTIVITY:

This will be demonstrated in a hands-on way using a simple manometer of fixed height filled with a fixed volume of water (not completely full). One end of the manometer will be open to ambient pressure and the other end will be connected to a reservoir with a controlled pressure. The students will be able to increase the pressure in the reservoir (via pump/compressor/etc.) or decrease it (via a release valve). This will cause the water to either rise or fall vertically. Each of the reservoirs features a pressure gauge and the manometer is marked for vertical length on both parts. Using measured ambient pressure and the characteristics of the water, data can be taken and compared to equation or the equation can be used to predict data that can then be tested. There will be a preface and an introduction to density and the equation via the computers and projectors. The students will then demonstrate that the equation works and is true via the manometers and some calculations using the computers. Once the students have had some experience with operating the air-tank to influence the manometer, the students will be split up into groups of 3 in order to test out their skills in a competition. Each team will be given two manometers to operate, and some set height differences that they have to accomplish. They will compete to see which team can most quickly and accurately achieve their specific height differentials in both manometers. They can accomplish this however they wish, but using the equation will be the most accurate way will be intuition based trial and error. Based on time and need, the concept of the water air-lock will be explained since it is completely based on this principle which reinforces the concept of density. The concept of conservation of mass in a closed system can also be touched upon for more advanced students using the computers and the projector to prove that since density is conserved in Bernoulli's equation using a manometer, then mass is conserved in the manometer since it is a closed system because the volume of water remains constant and density is mass divided by volume.

Proposal Appendix

Image 1:



Bernoulli's Equation

$$\frac{V^2}{2} + g\,z + \frac{P}{\rho} = \text{Constant}$$

Static therefore V1 = V2 = 0

g = accelaration due to gravity = constant

$$\rho_1 = \rho_2 = \rho_{H_2O} = \rho = \text{constant}$$

ρ = Density = Mass / Volume

P_1 = pressure on surface of moon

P_2 = pressure inside of base

z_1 = 0 Arbitrary **z = verticle height**

***** Advanced topic: Mass is conserved in the system since density is conserved (the density of water does not change). Since the density does not change and the volume remains constant, the mass must remain constant as well (rho=m/*v*). Therefore, mass is conserved. *****

Change in Z allows $p_1 \neq p_2$

while maintaining equilibirum (Bernoulli Equation = Constant)

$$\underset{0}{\cancel{\frac{V_1^2}{2}}} + g\underset{0}{\cancel{z_1}} + \frac{P_1}{\rho} = \underset{0}{\cancel{\frac{V_2^2}{2}}} + g z_2 + \frac{P_2}{\rho}$$

$$\downarrow$$

$$\frac{P_1}{\rho} = gZ + \frac{P_2}{\rho}$$

$$\downarrow$$

Simplified Bernoulli Equation

$$Z = \frac{P_1 - P_2}{\rho g}$$

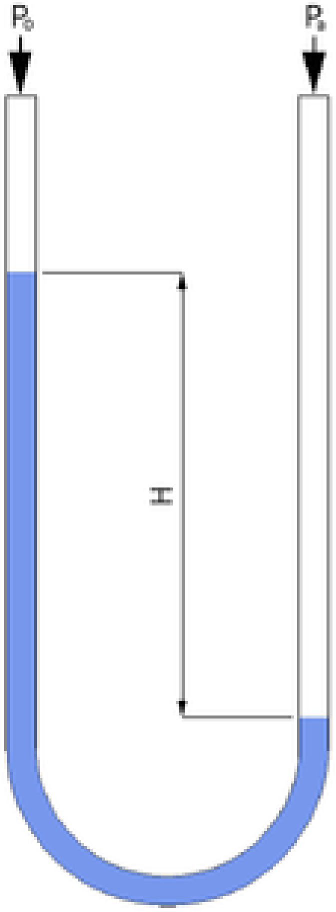
There is no fluid velocity at either end so both "v"s are equal to 0.

One of the "z" height components can be arbitrarily set as a 0 (zero) point. The other "z" then becomes the verticle distance (height) above (+) or below (-) the arbitrary zero OR the verticle distance between the two "z"s.

g (moon) = 1.6249 $\frac{m}{s^2}$

ρ water = 1000 $\frac{kg}{m^3}$

Image 2



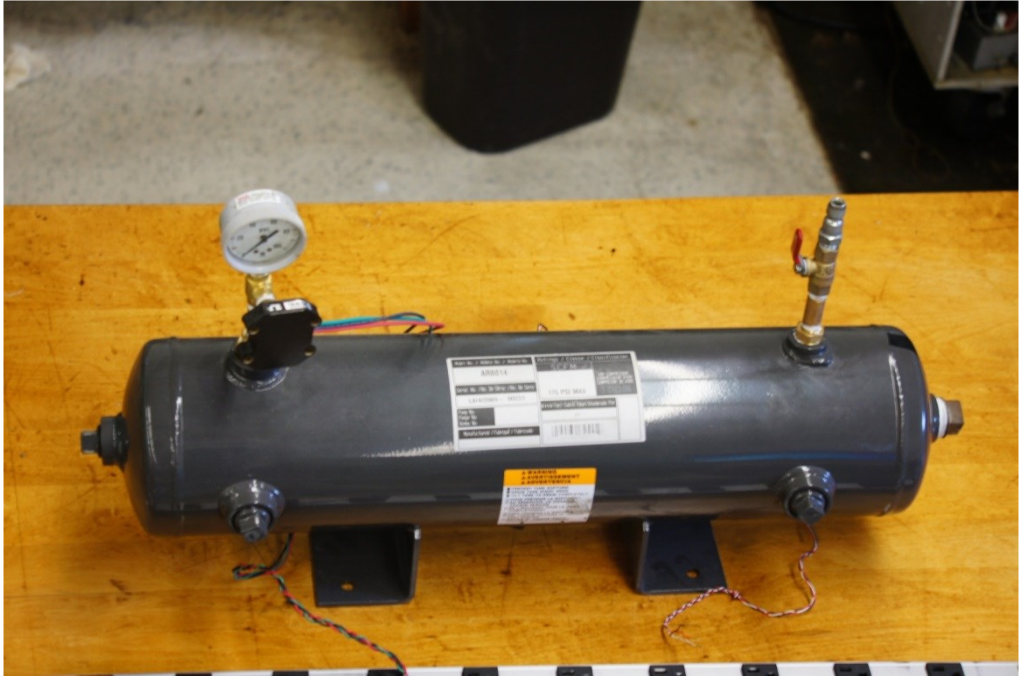
The difference in fluid height in a liquid column manometer is proportional to the pressure difference.

$$x = \frac{P_a - P_o}{g\rho}$$

Image 3

U-Tube Manometer with height markings
Courtesy of Sharpinstruments

Image 4



SPEEDAIRE AIR TANK FITTED WITH OMEGA ANALOG PRESSURE GAUGE

Mission Control Exhibit Proposal

1. Radiation (Earth Science Standard 3 pg. 32)

- Educational/ interactive videos on how the process of heat transfer via radiation works. The videos will deal with the topic in varying levels of depth based on need and touch upon it as a potential danger of a moon base.
- Once the concept is explained the concepts of shielding and protection can also be explained via educational video based on need and level of education/previous exposure. Topics can include water as a source of shielding, how much regolith would be needed for shielding, creative design ideas for moon base to protect against radiation, etc.

2. Lunar Habitation

- Graphic/Video Representation of what the living quarters of moon base inhabitants would look like
- Graphic representation of base construction. The base is constructed of many layers each with their own unique purpose. The base is also constructed mainly of materials created out of raw materials local to the moon, usually found in regolith. The base's structure layers from outermost to innermost are: Lunarcrete (concrete made of regolith), fiberglass (from silica found in regolith), aluminum (found in regolith and used to conduct electricity), and a second layer of fiberglass (used to completely insulate the aluminum as well as provide an extra layer of base insulation).
- This part would also discuss some of the necessities of lunar living including base pressure, temperature, oxygen levels, etc.
- A description of standard living conditions (square footage per person, facilities, etc.) as

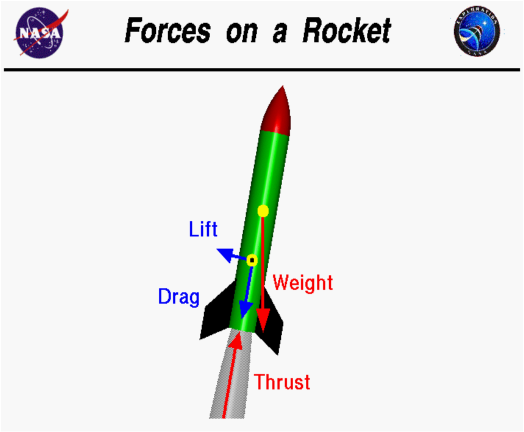
well as a description of how the base and personnel functioned (work vs. free time, shifts, meals, etc.) would also be included.

3. Communications (Technology/Engineering Standards 3.1/3.3 pg. 88)

- Compare/contrast audio and visual communications. Video explaining differences, need for one or the other, On Moon vs Earth ⇔Moon.
- Receiver + Transmitter possible explanatory video
- Possible game dealing with phases of the moon/communication at once. Involving basic math, algebra, and pre-algebra based on grade level.

4. Transport Technology (Standard 6.4 pg. 89)

- Explain forces on a space shuttle when taking off/landing and when in space.
- Video and possible educational game involving math and basic physics concepts.
- Video to touch upon the differences between acceleration due to gravity (g), drag force, lift force vs thrust, and impact that different g and atmospheres (or lack thereof) have on these forces. Reinforces W=mg (weight = mass x acceleration due to gravity).



The mission control room is in the shape of a circle with computer work stations arranged in a torus (donut) in the center of the room. Inside the center of the workstations is another arrangement of large screens on which information is displayed. Each of the workstations has a clear view of at least one of the screens. Students will sit down at the workstations and learn about one or more of the educational topics via videos presented on the computers or on the screens. The students could each have their own computer or share based on the grade level and the topic(s) being covered. Students would also get a grade level specific overview of lunar habitation as the mission control would also be used to "monitor the base and its personnel". After the educational video as the habitation overview were completed, the students would participate in a game-like activity that involved teamwork and rapid decision making based upon what the students learned. The activity would involve the students monitoring any aspect of the base related to the topics that they learned about. A problem would present itself, but only on one of the monitors. The students would then have to communicate the fact that there is a problem to the rest of mission control. Once the entire mission control was alerted, the students would have to, as a whole, make decisions and take actions to remedy the problem. The faster the reaction, the easier it would be to solve the problem, and the better the final result would be. The longer it took the students to react as a whole, the bigger the problem would become, and the harder it would be to remedy. The students would either be successful as a team or fail as a team teaching them teamwork, and the team based approach that would be necessary in successfully running a mission control.

Greenhouse / Photosynthesis Exhibit Proposal

From Curriculum Framework pg. 53, Life Sciences (Biology) Grades 6-8:

2. *Recognize that producers (plants that contain chlorophyll) use the energy from sunlight to make sugars from carbon dioxide and water through a process called photosynthesis. This food can be used immediately, stored for later use, or used by other organisms.*

Activity: Testing for Starch in Plants

-To be conducted at 6 different stations (5 students per station) in a simulated lunar greenhouse with some living, photosynthesizing plants.

-Time required for activity: approx. 20-30 min

-Space: ≤ 1000 sq. ft.

-Adult supervision required

Materials:

3. 60 small green plants with leaves (2 per student)
4. 60 50-mL plastic beakers (2 per student)
5. 2 1-L glass beakers
6. 60 90x15-mm plastic petri dishes (2 per student)
7. 30 3-mL droppers (1 per student)
8. 750 mL of ethyl alcohol
9. 1L of water

10. 6 hot plates (1 per station)
11. 6 small pots (1 per station)
12. 500 mL of iodine solution
13. 30 pairs of tweezers (1 per student)
14. 6 pairs of heat-resistant gloves
15. 30 pairs of safety goggles
16. 30 pairs of disposable gloves
17. 30 lab aprons

Procedure:

Keep one small plant in darkness for 24 hours before experiment. Keep other small plant in “greenhouse”, under light. *Optional: Students bring in prepared plants that they have grown in classrooms.*

5. Put on safety goggles, lab aprons, and gloves.

Steps 2-4 to be done by an adult supervisor at each station:

6. Pour water into small pot. Place pot on hot plate and boil water.
7. Pour 750 mL of ethyl alcohol into 1-mL glass beaker. Sit beaker in pot of boiling water. When ethyl alcohol begins to boil, remove beaker from the pot using heat-resistant gloves and turn off hot plate.
8. Carefully, pour hot water into one petri dish per student. Pour 25 mL of heated ethyl alcohol into one 50-mL plastic beaker per student. Pour 25 mL of iodine solution into

other plastic beaker.

9. Using tweezers, place leaves from both plants in hot water for approximately 60 seconds.
10. Remove leaves from water and place in beaker of ethyl alcohol from approximately 2 minutes until the leaves turn almost white. Using tweezers, remove leaves from alcohol and place in empty petri dish.
11. Using dropper, place drops of iodine solution on the leaves and watch what happens.
12. Ask students why they think this happened.
13. Explain concepts of experiment and photosynthesis.
14. (If enough time), Repeat experiment with variegated leaves from plants kept in light. Ask students where they think starch will be indicated in the leaf.

Results:

The hot water kills the leaf and the ethyl alcohol breaks down the chlorophyll, removing the leaves' green color. When the iodine solution is placed on the colorless leaves, some will turn blue-black and the others will turn reddish-brown. The iodine solution indicates presence of starch in the blue-black leaves. The reddish-brown leaves contain no starch. In the variegated leaves (green and white), the indicator would turn the once green parts blue-black, and the white parts reddish-brown.

Concepts:

The presence of starch (a product of photosynthesis) in the leaf means that the plant was photosynthesizing. Plants need light to perform photosynthesis; therefore the blue-black leaves are from the plants that were kept in light. The reddish-brown leaves are from the plants that were kept in the dark. Plants need chlorophyll to perform photosynthesis. Therefore, starch is produced in the green parts of variegated leaves, but not in the white parts.

C3 & C4 Plants:

The greenhouse would include both C3 and C4 plants for realism as well as to expose the students to two of the three types of photosynthesis. The lab experiment could be performed with either type of plant but the C3 plants would be kept in a carbon-dioxide rich environment, twice the normal atmospheric level, most of the time. This is because C3 plants thrive in environments that have much higher carbon dioxide levels than C4 plants which thrive in the earth's current carbon-dioxide levels.

The photosynthesis-starch experiment could be performed with either the C3 or the C4 plants. C4 plants are more efficient in the amount of water they use and synthesizes better under intense light and warmer temperatures. C3 plants are more efficient under normal conditions or under normal sunlight, cool conditions, and moist conditions. The experiment could be tweaked based on their characteristics and the conditions that they are exposed to if necessary. This could be used to highlight their differences and the different ways that they work in.

The C3 & C4 plants could also be used to teach a small lesson on evolution, if necessary, as the C3 plants existed before C4 and thrived in the high carbon-dioxide atmosphere present thousands to tens of thousands of years ago, around ten times the carbon-dioxide.

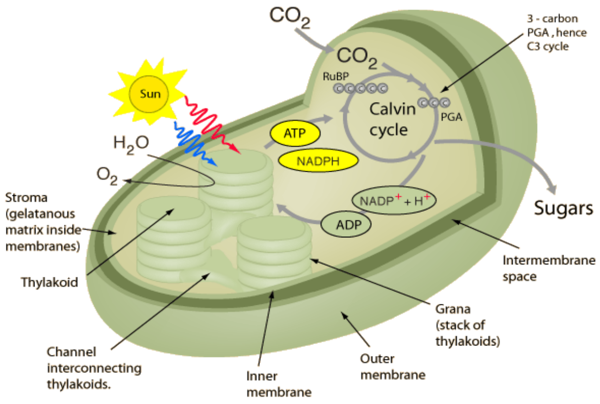
Process of Photosynthesis:

Included in explanation:

- Location of photosynthesis in plant
- Formula for photosynthesis
- How plants use the products of photosynthesis

- How humans exhale carbon dioxide, which is recycled from air in lunar base into greenhouse

Images for Explanation:



$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} \xrightarrow{\text{Light}} \underset{\text{Sugar}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2}$$

Design of Exhibit:

- Simulated lunar greenhouse with prop plants or images/videos of inside a greenhouse
- Six round Lab stations with five chairs at each
- One adult supervisor will walk around each lab table and assist students

Robots Exhibit Proposal

Student Goal: Build and program a robot that can face the moon's terrain and harvest regolith.

Regolith will be displayed in different color balls to represent level of difficulty.

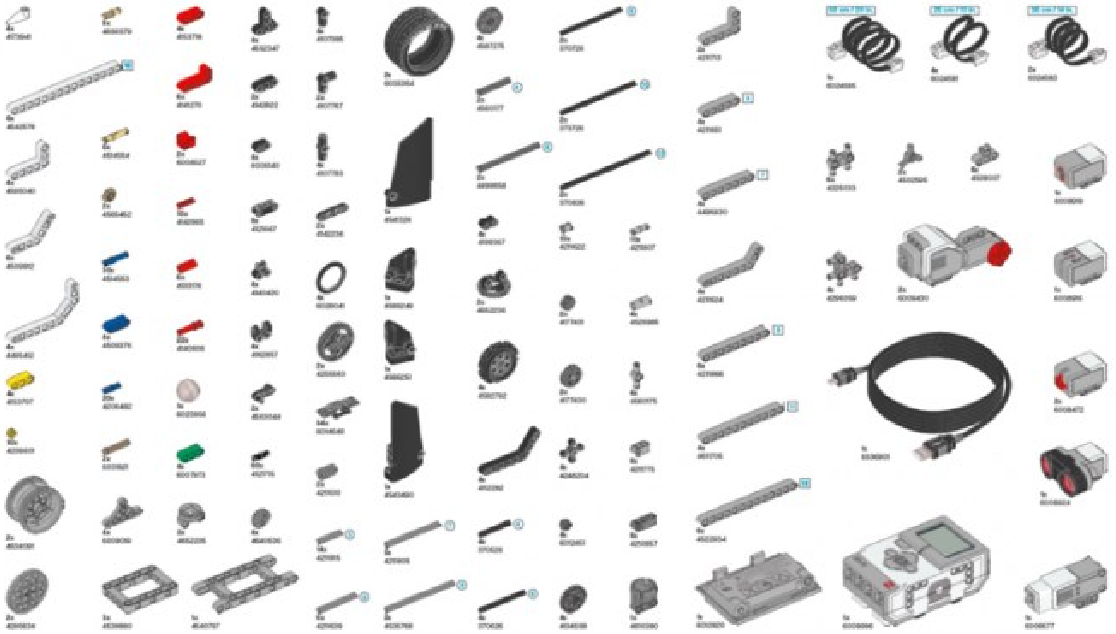
Exhibit A:

Manufacturing Technologies (4.1-4.3)

Teams of 4 build a robot that will venture across lunar terrain and harvest regolith.

Time: 30-40 minutes.

Kits will be provided using Mindstorm kits. The core set contains 400+ Lego elements including the EV3 brick, 2 large motors, 1 medium motor, an ultrasonic sensor, a pair of touch sensors, a gyro sensor and a color sensor. The expansion set, which could be bought separately, contains 600+ Lego elements.



This will demonstrate custom manufacturing systems by teams working differently to show creativity, and show how interchangeable parts/ robotics work.

Exhibit B:

Transportation Technology (6.1-6.3)

Teams of 3 program a robot to scout out certain objects in specific areas throughout the terrain to test the robot's functions.

Time 30-40 minutes

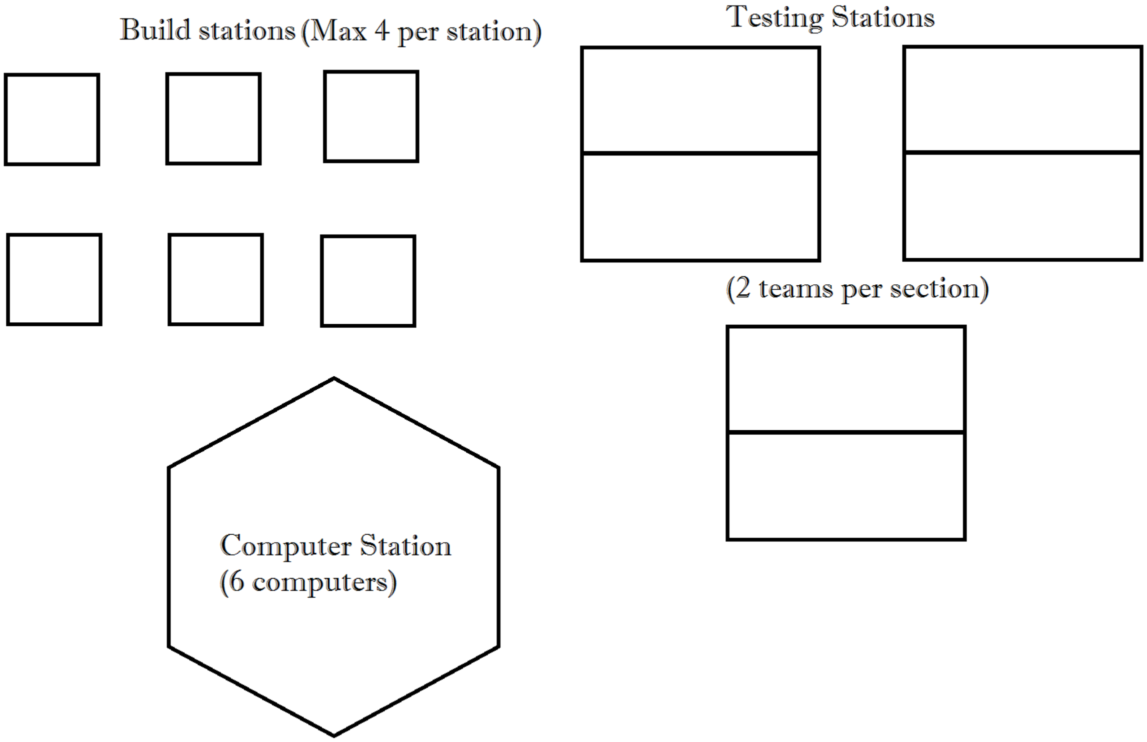
Terrain: It will have slick portions to mimic icy conditions on the moon. The rest of it will have a material with the same consistency as regolith. The robots will also have to traverse a crater-like hill in order to pick up the colored balls that represent regolith.

Examples of what kit can do:

Color sorting: http://www.youtube.com/watch?v=ldED7tWH_Sg

Basic programming: http://www.youtube.com/watch?v=m-XcGt8CsWc

Station Setup



Workstations are 3’x3’ tables standing roughly 2’ above the floor with roughly 3.5’ between each workstation.

Teams will sit opposite each other at the computer station. They will use the computer station to program their robots.

The testing stations are composed of two 3.25’ by 6.67’ tables. The tables pushed together. This allows teams to compete directly against each other.

Regolith Exhibit Proposal

Proposed Number of Students for Exhibit: Max 30 + Educators/Chaperones

Proposed Time Spend in Exhibit: 30 Minutes

Proposed Space for Exhibit: ~4000 ft^2

Large "pit" where the "regolith" will be stored

Regolith is composed of different color balls to represent the chemical breakdown with each different element also being a different size.

Work stations around the regolith with areas to collect the different elements

1. Students walk into the sorting room and are introduced to the concept of the regolith, moon soil.
2. Students then have to decide if the regolith is a mixture or pure substance.
    a. P.67 Standard 8 for Gr 6-8 (Differentiate between mixtures and pure substances)
3. Students are then divided into 8 equal groups and asked to separate the different chemicals in the regolith. After a few minutes of doing it by hand they are asked what could make separating easier and faster.
    a. P. 87 Standard 1.2 for Gr 6-8 (Identify and explain appropriate measuring tools, hand tools, and power tools used to hold, lift, carry, fasten, and separate, and explain their safe and proper use.)
4. Give the groups a "tool" and ask them to use the tool to separate the elements in the most effective way and compare the different ways to sort the chemicals.
    a. P. 87 Standard 2 for Gr 6-8

       2.1 Identify and explain the steps of the engineering design process, i.e., identify the need or problem, research the problem, develop possible solutions, select the best possible solution(s), construct a prototype, test and evaluate, communicate the solution(s), and redesign.

    2.3 Describe and explain the purpose of a given prototype.

    2.5 Explain how such design features as size, shape, weight, function, and cost limitations would affect the construction of a given prototype.

5. For the final step, the students will take the wax and melt it down. They will then pour the wax into molds, which when submerged into cold water will harden. This process gives an example of material processing via heat, which is a way to separate materials in compounds.
    a. P. 68 Standard 9 (Recognize that a substance (element or compound) has a melting point and a boiling point, both of which are independent of the amount of the sample.)
    b. P.68 standard 10 (Differentiate between physical changes and chemical changes.)

The tool will be used to sort the chemicals with a "plinko" type peg system. The system would have a bunch of holes placed and the pegs unattached. The students would be given 20 minutes to build and test their tool.

Key point: Stress that to break down and separate regolith would be much more complicated and a chemical process. This is just a rough demonstration of why specialized tools are needed and how they are developed.

Annotated Background Research Sources (By Subject)

Lunar Logistics/Danger + Nuclear Power On & Off the Moon

O'Neill, Ian. "Building a Moon Base: Part 1 – Challenges and Hazards." Universe Today. 07 Feb. 2008. <http://www.universetoday.com/12726/>.

O'Neill, Ian. "Building a Moon Base: Part 2 – Habitat Concepts." Universe Today RSS. 09 Feb. 2008. <http://www.universetoday.com/12758/building-a-base-on-the-moon-part-2-habitat-concepts/>.

O'Neill, Ian. "Building a Moon Base: Part 3 – Structural Design." Universe Today RSS. 20 Feb. 2008. <http://www.universetoday.com/12864/building-a-base-on-the-moon-part-3-structural-design/>.

O'Neill, Ian. "Building a Moon Base: Part 4 – Infrastructure and Transportation." Universe Today RSS. 22 Mar. 2008. <http://www.universetoday.com/13216/building-a-base-on-the-moon-part-4-infrastructure-and-transportation/>.

These four sources are all parts of a cumulative work by Ian O'Neill that discuss the logistics and dangers of building a base on the moon. Each one of these articles deals with a different portion of the logistics and dangers. They are all based upon research by Haym Benaroya and Leonhard Bernold ("Engineering of lunar bases").

World Nuclear Assn. "Nuclear Reactors for Space." Nuclear Reactors for Space. May 2013. <http://www.world-nuclear.org/info/Non-Power-Nuclear-Applications/Transport/Nuclear-Reactors-for-Space/>.

This is an overview of nuclear power use in space both in propulsion and general power use. It covers fission and fusion as well as outlines examples of their use over their years in a chronological manner.

Aftergood, Steven. "Background on space nuclear power." *Science & Global Security* 1.1-2 (1989): 93-107.

This is a slightly dated but very comprehensive background on nuclear power in space. It looks at all of the different facets regarding this topic up to the date that it was published.

General Assembly of UNOOSA. "Principles Relevant to the Use of Nuclear Power Sources In Outer Space." UNOOSA. 2013. United Nations Office for Outer Space Affairs. <http://www.unoosa.org/oosa/SpaceLaw/nps.html>.

This article is the United Nation's Policy on the use of Nuclear power in space. The policies that relate to safety and use of nuclear reactors are particularly informative and helpful.

Werner, James E. "The first nuclear power plants for settlements on the Moon & Mars." American Chemical Society 28 Aug. 2011. <http://www.acs.org/content/acs/en/pressroom/newsreleases/2011/august/the-first-nuclear-power-plants-for-settlements-on-the-moon-mars.html>.

This article is about the concept, prototyping and, design of the first nuclear power plants for moon colonization that will be built by NASA in 2012. This is a very compact nuclear fission power plant.

International Atomic Energy Agency. "Nuclear Power on the Moon." IAEA. <http://www.iaea.org/Publications/Magazines/Bulletin/Bull121/12104700912.pdf>.

This is an article about nuclear power on the moon by the international atomic energy agency. It talks about the concept while giving specifications, information on operation, and advantages and disadvantages of the technology

Greenhouse & Biology

Article on collapsible lunar greenhouse prototype at Uni. of AZ.
SPACE.com Staff. “Lunar Greenhouse Could Grow Food For Future Moon Colonies.”*Space.com*.p.,19 October 2010.Web.12 September 2013.<http://www.space.com/9353-lunar-greenhouse-grow-food-future-moon-colonies.html >.

Article on NASA's discovery of ice in craters on North Pole.
Malik, Tariq. “Tons of Water Ice Found on the Moon's North Pole.”*Space.com*.p.,01 March 2010.Web.20 September 2013.<http://www.space.com/7987-tons-water-ice-moon-north-pole.html >.

Four-part article on building a moon base, based on research by Haym Benaroya and Leonhard Bernold (“Engineering of lunar bases”).
O'Neill, Ian. “Building a Moonbase: Part 1 – Challenges and Hazards.”*Universe Today*.p.,07 February 2008.Web.20 September 2013.<http://www.universetoday.com/12726/building-a-base-on-the-moon-challenges-and-hazards/ >.

O'Neill, Ian. “Building a Moonbase: Part 2 – Habitat Concepts.”*Universe Today*.p.,09 February 2008.Web.20 September 2013.<http://www.universetoday.com/12758/building-a-base-on-the-moon-part-2-habitat-concepts/ >.

O'Neill, Ian. “Building a Moonbase: Part 3 – Structural Design.”*Universe Today*.p.,20 February 2008.Web.20 September 2013.<http://www.universetoday.com/12864/building-a-base-on-the-moon-part-3-structural-design/ >.

O'Neill, Ian. “Building a Moonbase: Part 4 – Infrastructure and Transportation.”*Universe Today*.p.,22 March 2008.Web.20 September 2013.<http://www.universetoday.com/13216/building-a-base-on-the-moon-part-4-infrastructure-and-transportation/ >.

Robots & Robots in Space

Action Planner of Hybrid Leg-Wheel Robots for Lunar and Planetary Exploration
Rohmer, E.; Reina, G.; Ishigami, G.; Keiji Nagatani,; Kazuya Yoshida,, "Action planner of hybrid leg-wheel robots for lunar and planetary exploration," *Intelligent Robots and Systems, 2008. IROS 2008. IEEE/RSJ International Conference on* , vol., no., pp.3902,3907, 22-26 Sept. 2008
doi: 10.1109/IROS.2008.4651134
Abstract: In this paper, we propose an action planning algorithm and its evaluation method based on dynamic simulation for a novel type of hybrid leg-wheel rover for planetary exploration. Hybrid leg-wheel robots are recently receiving a growing interest from the space community to explore planets, since they offer an appropriate solution to gain improved speed and mobility on unstructured terrain. However, in order to fully reach the hybrid mechanismpsilas potential, it is necessary to establish an optimal way to define when to use one over the other locomotion mode, depending on the soil conditions and topology. Even though this step is crucial, little attention has been devoted to this topic by the robotic community. The switching of motion mode, that is either wheel or leg are the actions to be planned, that we are considering in this paper. We aim at generating the safest and the least energy demanding path to reach a point of scientific interest. In order to define the optimal path with the set of switching actions required for the robot to follow it, the authors developed an action planning algorithm and a path evaluation method based on a four steps approach. First, an optimal candidate path on a rough terrain is generated based on topology and specificationspsila criteria functions. Then switching actions are defined along this path depending on the hybrid robotpsilas performances in each motion mode. The next step is a dynamic simulation of the robot controlled to follow the path. Finally, the path is evaluated based on the energy profile spent by the actuators and calculated by the simulation. Demonstrations for the proposed technique are addressed along with a discussion on characteristics of the candidate path and the energy profile of the robot.
keywords:
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4651134&isnumber=4650570

LUNARES: lunar crater exploration with heterogeneous multi robot systems
http://link.springer.com.ezproxy.wpi.edu/article/10.1007%2Fs11370-010-0081-4# ←
LUNARES: lunar crater exploration with heterogenous multi robot systems, article is about a scenario of robots residing in the Shakelton crater in the south pole using both wheeled and legged rovers. (no cite available)

Human-Robot Lunar Exploration: Pressurized vs. Unpressurized Rovers
Weisbin, C.; Mrozinski, J.; Hua, H.; Shelton, K.; Smith, J.H.; Elfes, A.; Lincoln, W.; Adumitroaie, V.; Silberg, R., "Human-Robot Lunar Exploration: Pressurized vs. Unpressurized Rovers," *Systems Engineering, 2008. ICSENG '08. 19th International Conference on* , vol., no., pp.8,12, 19-21 Aug. 2008
doi: 10.1109/ICSEng.2008.10
Abstract: A study is conducted to determine the relative productivity of employing two pressurized or two unpressurized robotic rovers with two teams of astronauts to accomplish a

group of activities on the Moon. An automated planning tool is used to calculate the optimal sequence of events, given an objective function and sets of assumptions and constraints. For the mission scenario studied, a pair of pressurized rovers is shown to be about 7 times as productive as a pair of unpressurized rovers when calculating benefits divided by marginal operational costs. This is primarily due to a constraint that limits astronauts to a maximum of 8 hours per day in space suits. The unpressurized rovers require the astronauts to wear space suits at all times, severely limiting the distance they can travel from the lander-habitat; the pressurized rovers permit the astronauts to remove their suits while driving, monitoring robotic activities, and resting between work periods.
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4616605&isnumber=4616596

A Biologically Inspired Robot for Lunar Exploration and Regolith Excavation
Dunker, Philip A
In order for a long-term lunar base to be successful, resources must be gathered from its surroundings (*in situ* resource utilization). One of the most important resources for any human space mission is oxygen, which can be extracted from regolith on the lunar surface. The purpose of this research was to design, fabricate, and test a robot prototype for a lunar rover that would be able to explore the surface of the Moon, excavate a quantity of lunar regolith, and transport the regolith to a central oxygen extraction station. The cockroach-inspired Whegs™ robotic platform, which combines wheeled and legged locomotion using six three-spoked “wheel-leg” appendages, is well-suited for negotiating the rocky obstacles and loose material on the lunar surface. A new prototype robot was designed and constructed based upon the Whegs™ platform, and its performance on loose substrates was quantified. URL: Dunker, P. (2009). *A Biologically Inspired Robot for Lunar Exploration and Regolith Excavation.* (Electronic Thesis or Dissertation). Retrieved from https://etd.ohiolink.edu/

FRC Lunacy Rules (Exhibit mockup?)
http://www.usfirst.org/uploadedFiles/Consolidated%20Manual%20022409.pdf

FTC Body Rules (Combination with FRC)
http://www.usfirst.org/roboticsprograms/ftc/game

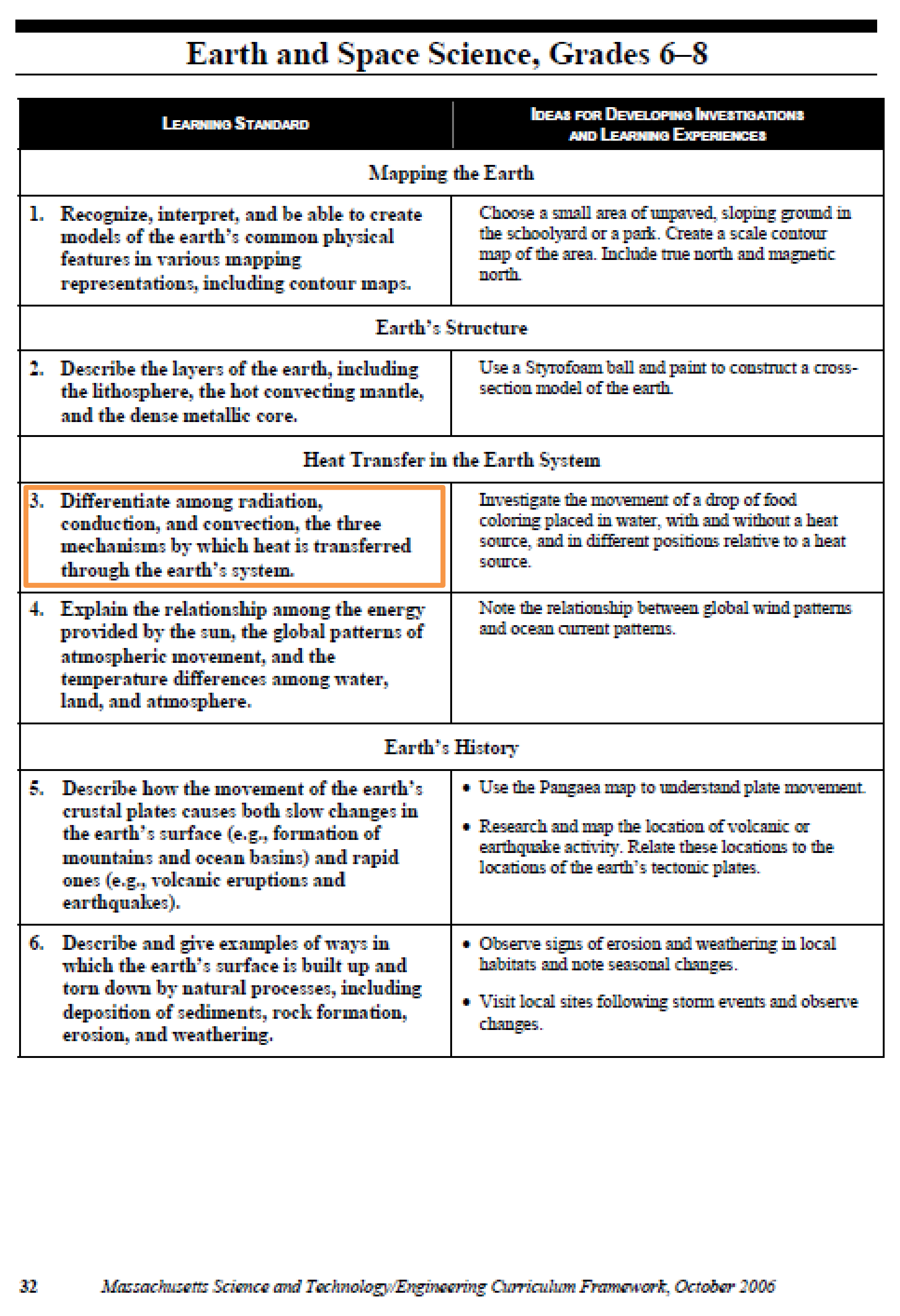
3D printing and medical-device development
Medical device innovation comes from small and nimble firms
- How best to harness new 3D-printing technologies
Written by:, Sean G., and LLC Boston 3D Printsmith. "3D Printing and Medical-Device Development." *Medical Design News*May 08 2012*ProQuest.* Web. 16 Oct. 2013 . URL: http://ezproxy.wpi.edu/login?url=http://search.proquest.com.ezproxy.wpi.edu/docview/1011593506?accountid=29120 ← With limited resources using 3D printing would be used for making medical equipment. *Not priority

3D Printing Coming to the Manufacturing Space - and Outer Space
Using materials such as metal, rubber, and plastic, 3D printers can create nearly anything that can be modeled in software, from custom shoes and hearing aids to complex airplane parts and even a car. These high-tech printers, which generated $1.4 billion in worldwide revenue for the industry last year, have typically been used to create prototypes of new products, but more

businesses are using them to produce finished goods. Unlike conventional manufacturing, where products are often mass-produced overseas, 3D printing allows companies to print customized items when and where they're needed, cutting the costs of materials and shipping goods like shoes from China to US store shelves and then to outlets if they don't sell. The technology, also called additive manufacturing, makes it possible to build products in remote places, such as outer space. As for the market, printer sales are closely tied to the research and development budgets of industries, such as consumer goods and manufacturing. King, Rachael. "3D Printing Coming to the Manufacturing Space - and Outer Space." *Business week* Apr 30 2012: 1.*ProQuest.* Web. 16 Oct. 2013 . URL: http://ezproxy.wpi.edu/login?url=http://search.proquest.com.ezproxy.wpi.edu/docview/1010975967?accountid=29120

Condensed Massachusetts Department of Education STEM Curriculum (Most Recent Version: 2006)

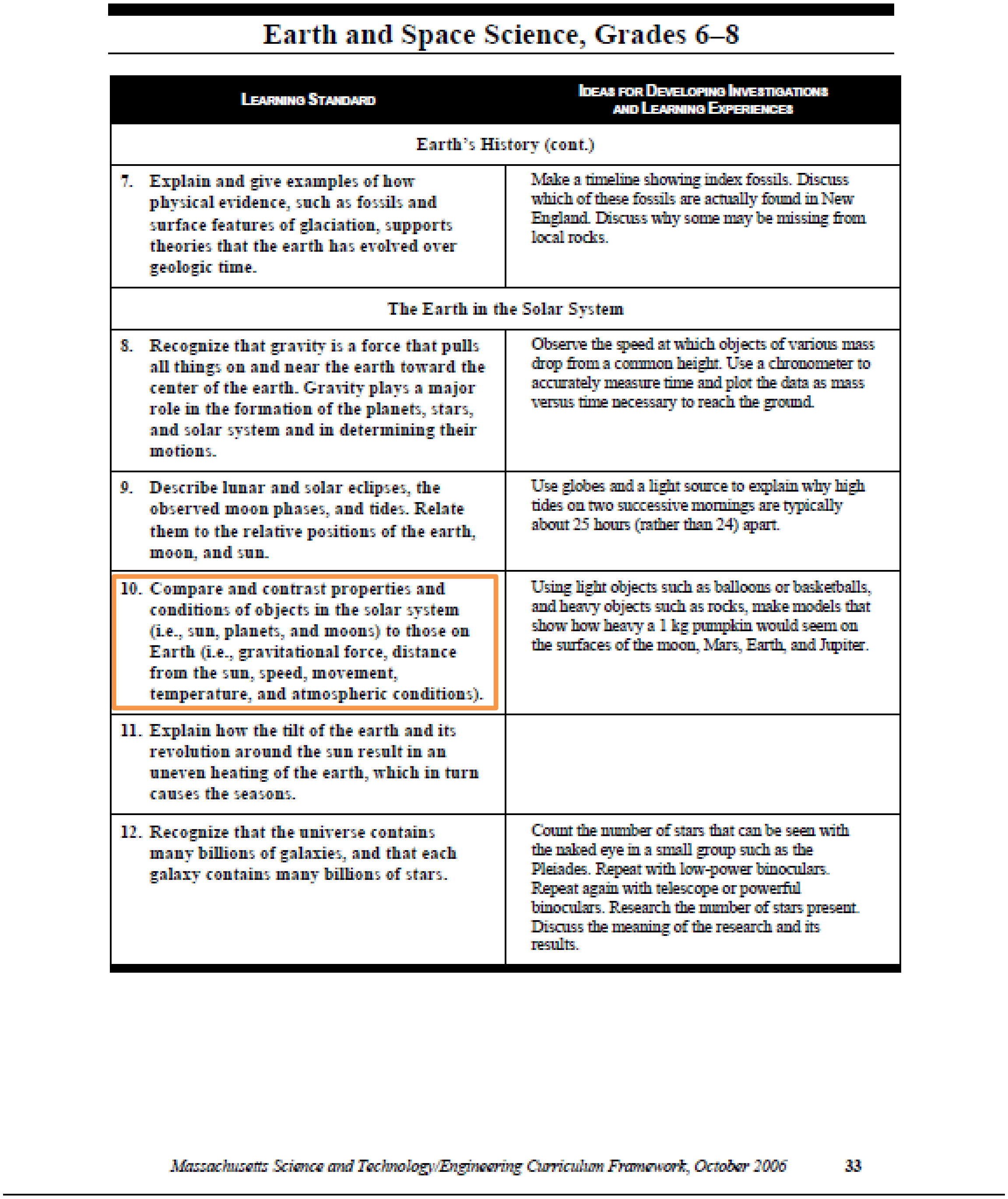
(Direct Link http://www.doe.mass.edu/frameworks/scitech/1006.pdf)
Note: Relevant Learning Standards are enclosed in orange boxes.



Earth and Space Science, Grades 6–8

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Mapping the Earth	
1. Recognize, interpret, and be able to create models of the earth's common physical features in various mapping representations, including contour maps.	Choose a small area of unpaved, sloping ground in the schoolyard or a park. Create a scale contour map of the area. Include true north and magnetic north.
Earth's Structure	
2. Describe the layers of the earth, including the lithosphere, the hot convecting mantle, and the dense metallic core.	Use a Styrofoam ball and paint to construct a cross-section model of the earth.
Heat Transfer in the Earth System	
3. Differentiate among radiation, conduction, and convection, the three mechanisms by which heat is transferred through the earth's system.	Investigate the movement of a drop of food coloring placed in water, with and without a heat source, and in different positions relative to a heat source.
4. Explain the relationship among the energy provided by the sun, the global patterns of atmospheric movement, and the temperature differences among water, land, and atmosphere.	Note the relationship between global wind patterns and ocean current patterns.
Earth's History	
5. Describe how the movement of the earth's crustal plates causes both slow changes in the earth's surface (e.g., formation of mountains and ocean basins) and rapid ones (e.g., volcanic eruptions and earthquakes).	• Use the Pangaea map to understand plate movement. • Research and map the location of volcanic or earthquake activity. Relate these locations to the locations of the earth's tectonic plates.
6. Describe and give examples of ways in which the earth's surface is built up and torn down by natural processes, including deposition of sediments, rock formation, erosion, and weathering.	• Observe signs of erosion and weathering in local habitats and note seasonal changes. • Visit local sites following storm events and observe changes.

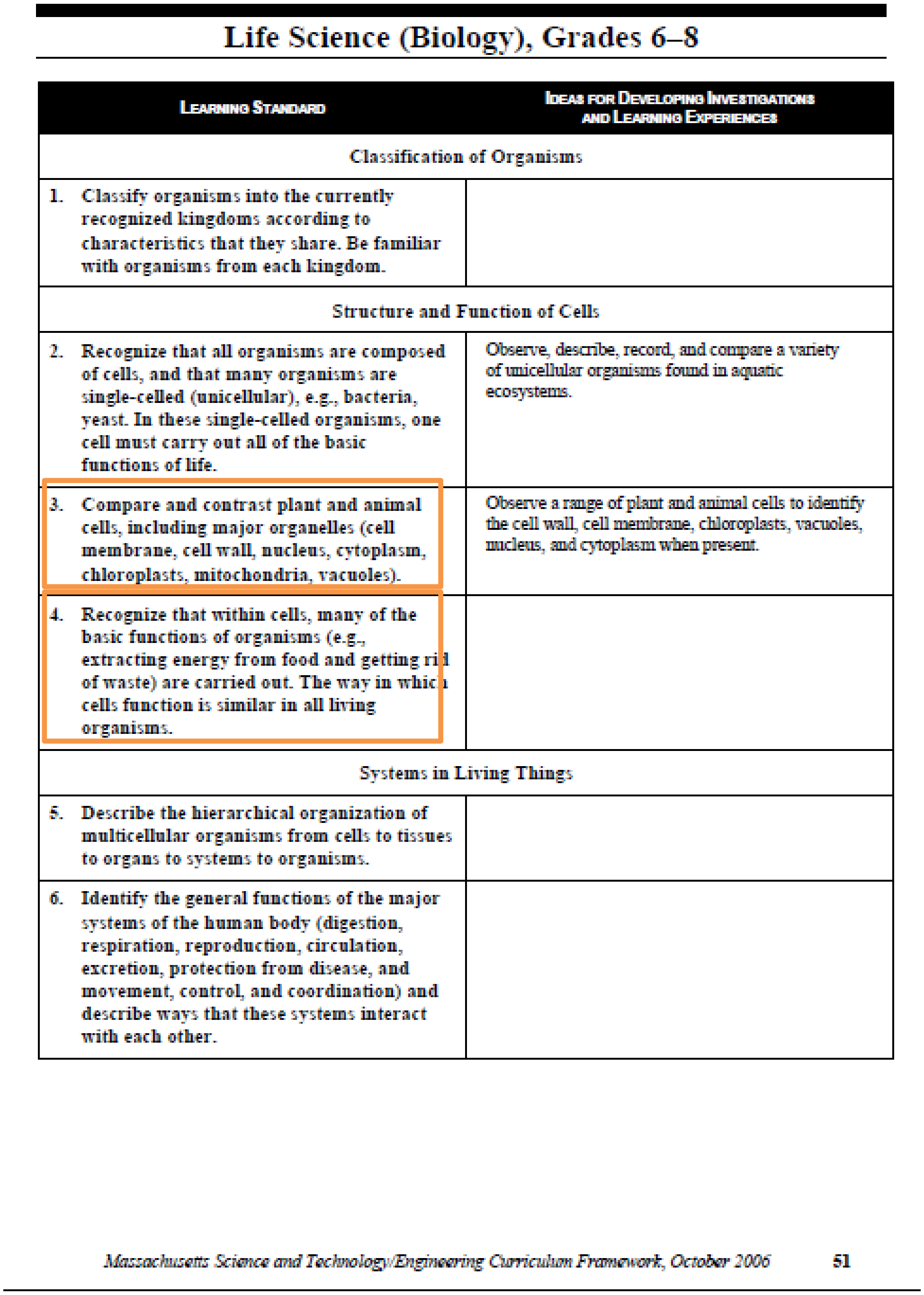
32 *Massachusetts Science and Technology/Engineering Curriculum Framework, October 2006*



Earth and Space Science, Grades 6–8

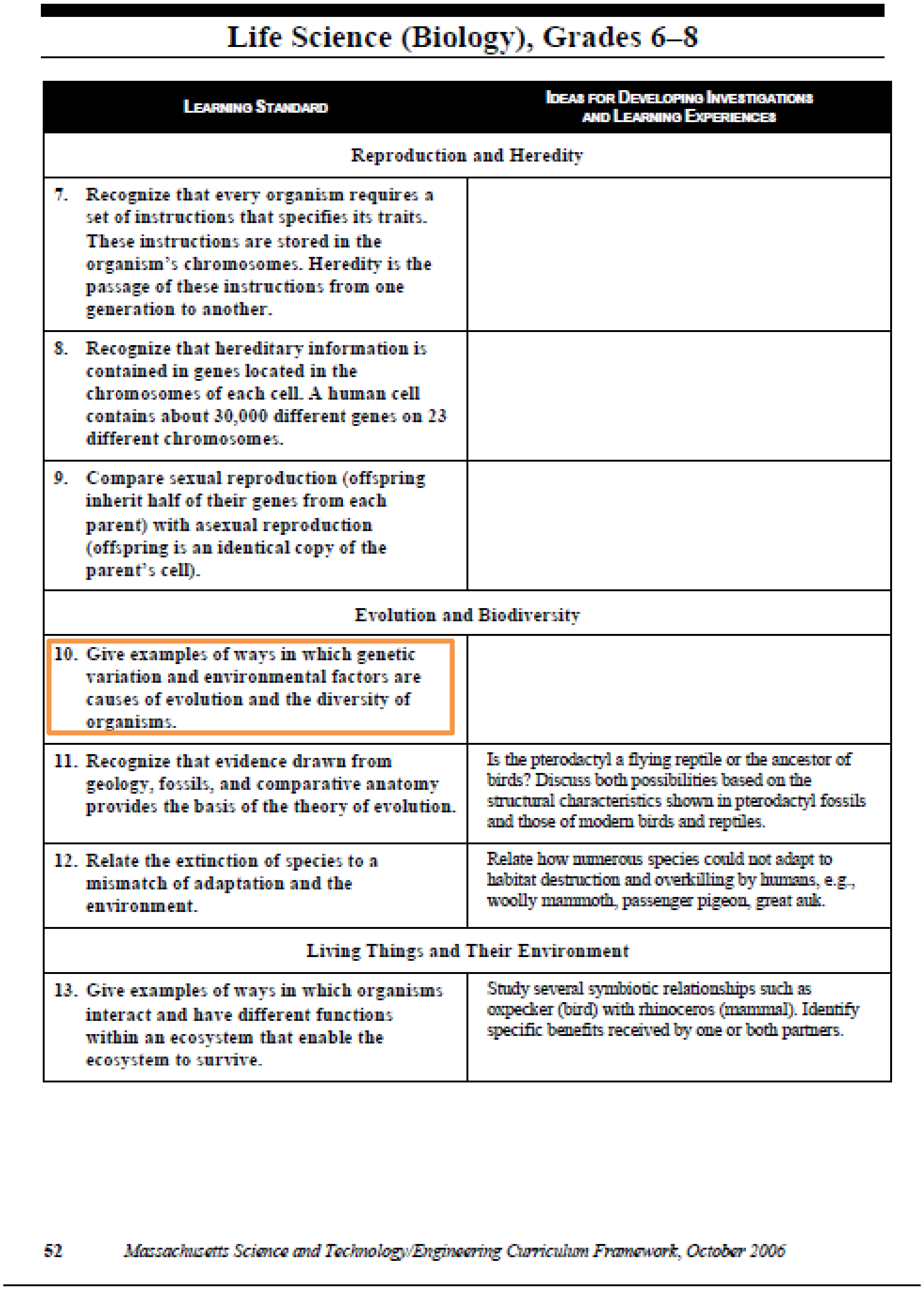
LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Earth's History (cont.)	
7. Explain and give examples of how physical evidence, such as fossils and surface features of glaciation, supports theories that the earth has evolved over geologic time.	Make a timeline showing index fossils. Discuss which of these fossils are actually found in New England. Discuss why some may be missing from local rocks.
The Earth in the Solar System	
8. Recognize that gravity is a force that pulls all things on and near the earth toward the center of the earth. Gravity plays a major role in the formation of the planets, stars, and solar system and in determining their motions.	Observe the speed at which objects of various mass drop from a common height. Use a chronometer to accurately measure time and plot the data as mass versus time necessary to reach the ground.
9. Describe lunar and solar eclipses, the observed moon phases, and tides. Relate them to the relative positions of the earth, moon, and sun.	Use globes and a light source to explain why high tides on two successive mornings are typically about 25 hours (rather than 24) apart.
10. Compare and contrast properties and conditions of objects in the solar system (i.e., sun, planets, and moons) to those on Earth (i.e., gravitational force, distance from the sun, speed, movement, temperature, and atmospheric conditions).	Using light objects such as balloons or basketballs, and heavy objects such as rocks, make models that show how heavy a 1 kg pumpkin would seem on the surfaces of the moon, Mars, Earth, and Jupiter.
11. Explain how the tilt of the earth and its revolution around the sun result in an uneven heating of the earth, which in turn causes the seasons.	
12. Recognize that the universe contains many billions of galaxies, and that each galaxy contains many billions of stars.	Count the number of stars that can be seen with the naked eye in a small group such as the Pleiades. Repeat with low-power binoculars. Repeat again with telescope or powerful binoculars. Research the number of stars present. Discuss the meaning of the research and its results.

Massachusetts Science and Technology/Engineering Curriculum Framework, October 2006 **33**



Life Science (Biology), Grades 6–8

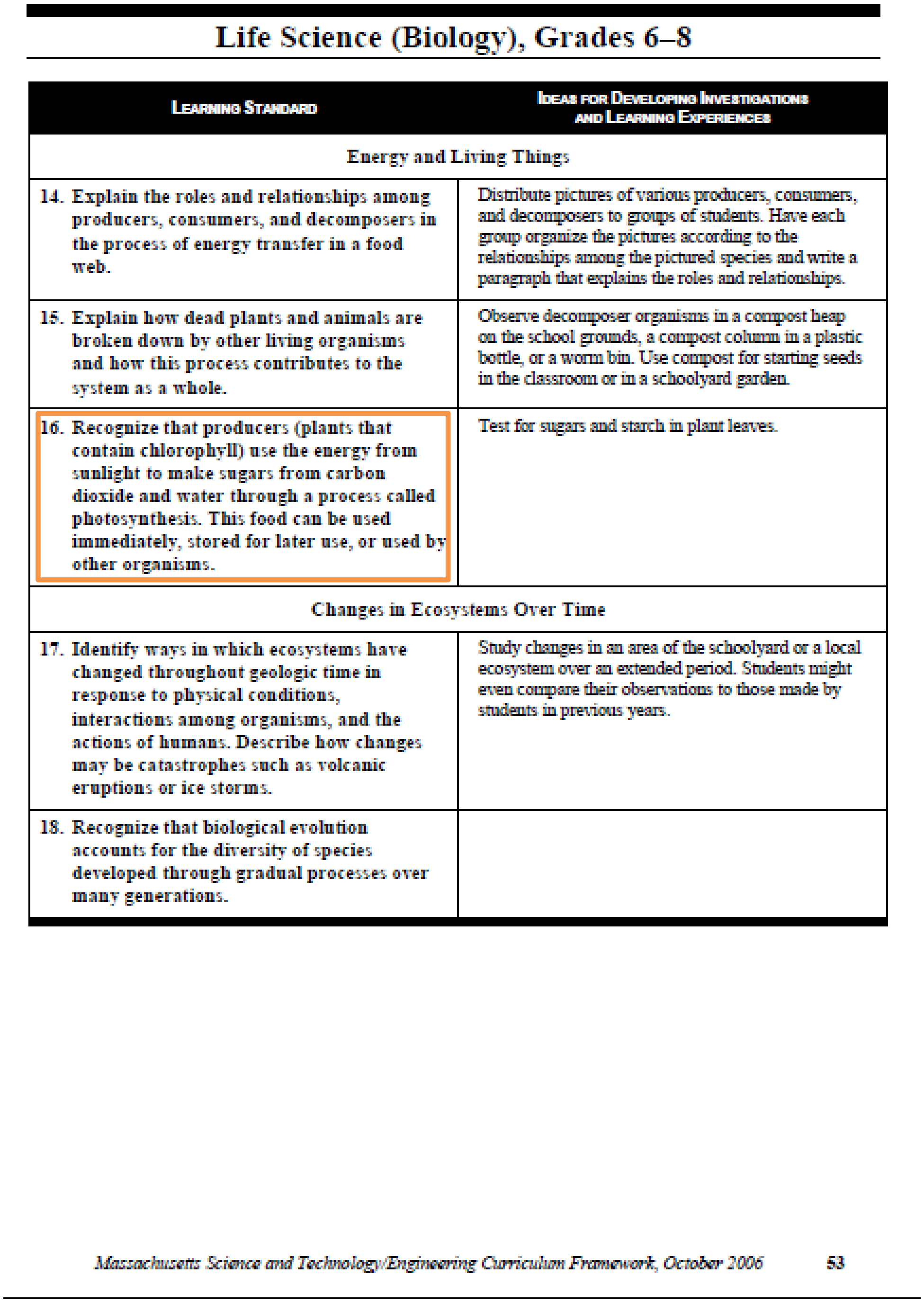
LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Classification of Organisms	
1. Classify organisms into the currently recognized kingdoms according to characteristics that they share. Be familiar with organisms from each kingdom.	
Structure and Function of Cells	
2. Recognize that all organisms are composed of cells, and that many organisms are single-celled (unicellular), e.g., bacteria, yeast. In these single-celled organisms, one cell must carry out all of the basic functions of life.	Observe, describe, record, and compare a variety of unicellular organisms found in aquatic ecosystems.
3. Compare and contrast plant and animal cells, including major organelles (cell membrane, cell wall, nucleus, cytoplasm, chloroplasts, mitochondria, vacuoles).	Observe a range of plant and animal cells to identify the cell wall, cell membrane, chloroplasts, vacuoles, nucleus, and cytoplasm when present.
4. Recognize that within cells, many of the basic functions of organisms (e.g., extracting energy from food and getting rid of waste) are carried out. The way in which cells function is similar in all living organisms.	
Systems in Living Things	
5. Describe the hierarchical organization of multicellular organisms from cells to tissues to organs to systems to organisms.	
6. Identify the general functions of the major systems of the human body (digestion, respiration, reproduction, circulation, excretion, protection from disease, and movement, control, and coordination) and describe ways that these systems interact with each other.	



Life Science (Biology), Grades 6–8

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Reproduction and Heredity	
7. Recognize that every organism requires a set of instructions that specifies its traits. These instructions are stored in the organism's chromosomes. Heredity is the passage of these instructions from one generation to another.	
8. Recognize that hereditary information is contained in genes located in the chromosomes of each cell. A human cell contains about 30,000 different genes on 23 different chromosomes.	
9. Compare sexual reproduction (offspring inherit half of their genes from each parent) with asexual reproduction (offspring is an identical copy of the parent's cell).	
Evolution and Biodiversity	
10. Give examples of ways in which genetic variation and environmental factors are causes of evolution and the diversity of organisms.	
11. Recognize that evidence drawn from geology, fossils, and comparative anatomy provides the basis of the theory of evolution.	Is the pterodactyl a flying reptile or the ancestor of birds? Discuss both possibilities based on the structural characteristics shown in pterodactyl fossils and those of modern birds and reptiles.
12. Relate the extinction of species to a mismatch of adaptation and the environment.	Relate how numerous species could not adapt to habitat destruction and overkilling by humans, e.g., woolly mammoth, passenger pigeon, great auk.
Living Things and Their Environment	
13. Give examples of ways in which organisms interact and have different functions within an ecosystem that enable the ecosystem to survive.	Study several symbiotic relationships such as oxpecker (bird) with rhinoceros (mammal). Identify specific benefits received by one or both partners.

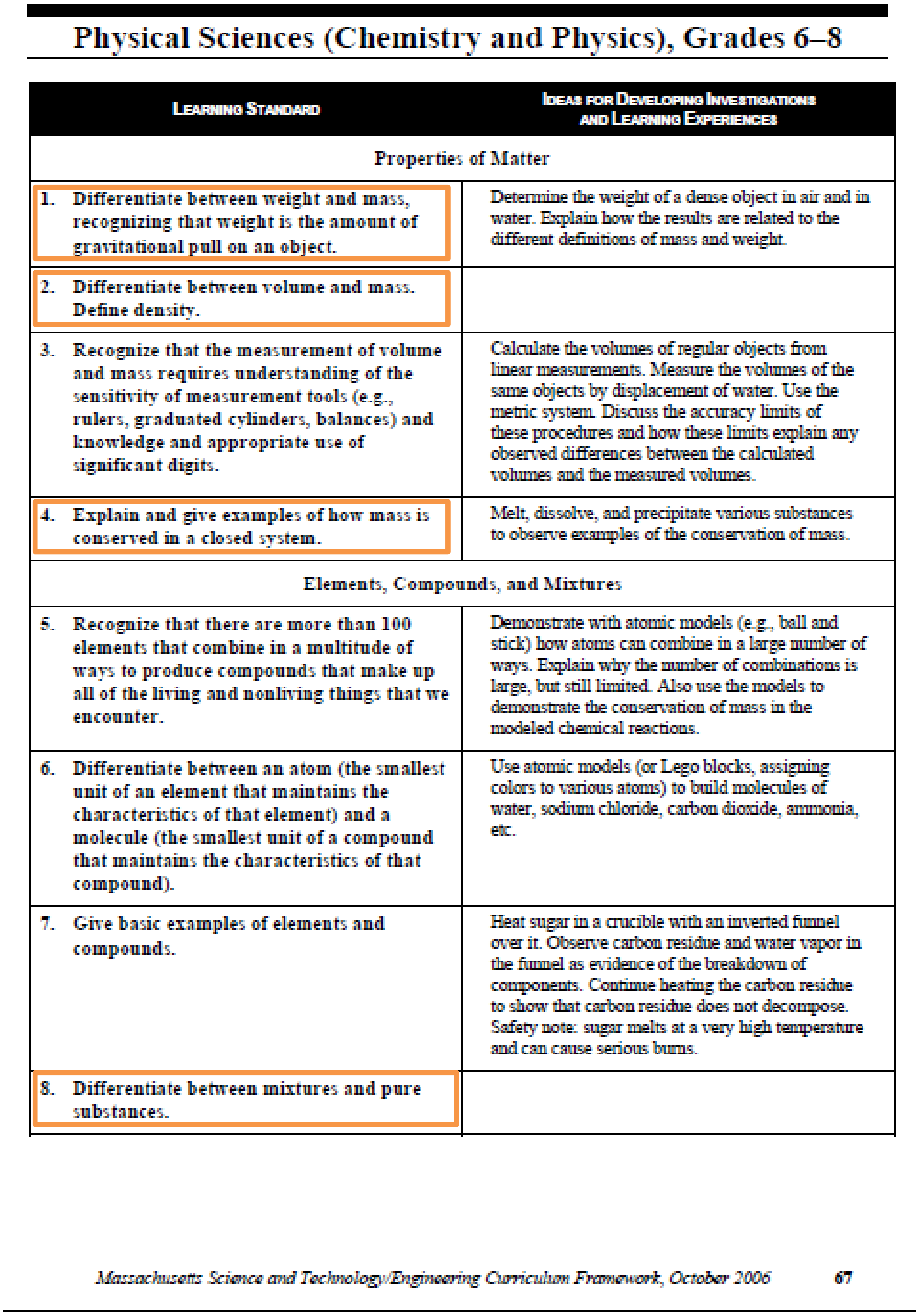
52 *Massachusetts Science and Technology/Engineering Curriculum Framework, October 2006*



Life Science (Biology), Grades 6–8

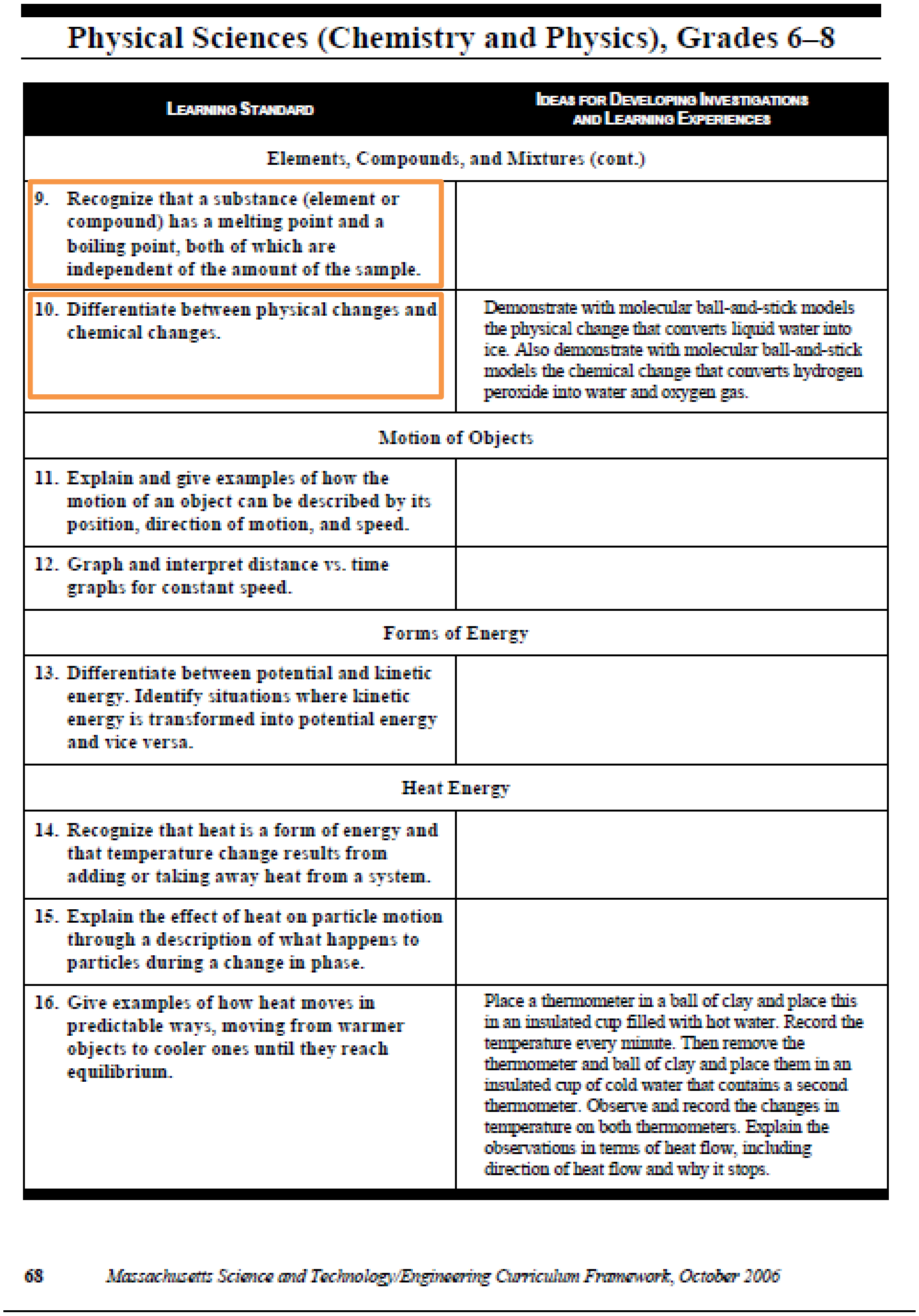
LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Energy and Living Things	
14. Explain the roles and relationships among producers, consumers, and decomposers in the process of energy transfer in a food web.	Distribute pictures of various producers, consumers, and decomposers to groups of students. Have each group organize the pictures according to the relationships among the pictured species and write a paragraph that explains the roles and relationships.
15. Explain how dead plants and animals are broken down by other living organisms and how this process contributes to the system as a whole.	Observe decomposer organisms in a compost heap on the school grounds, a compost column in a plastic bottle, or a worm bin. Use compost for starting seeds in the classroom or in a schoolyard garden.
16. Recognize that producers (plants that contain chlorophyll) use the energy from sunlight to make sugars from carbon dioxide and water through a process called photosynthesis. This food can be used immediately, stored for later use, or used by other organisms.	Test for sugars and starch in plant leaves.
Changes in Ecosystems Over Time	
17. Identify ways in which ecosystems have changed throughout geologic time in response to physical conditions, interactions among organisms, and the actions of humans. Describe how changes may be catastrophes such as volcanic eruptions or ice storms.	Study changes in an area of the schoolyard or a local ecosystem over an extended period. Students might even compare their observations to those made by students in previous years.
18. Recognize that biological evolution accounts for the diversity of species developed through gradual processes over many generations.	

Massachusetts Science and Technology/Engineering Curriculum Framework, October 2006 53



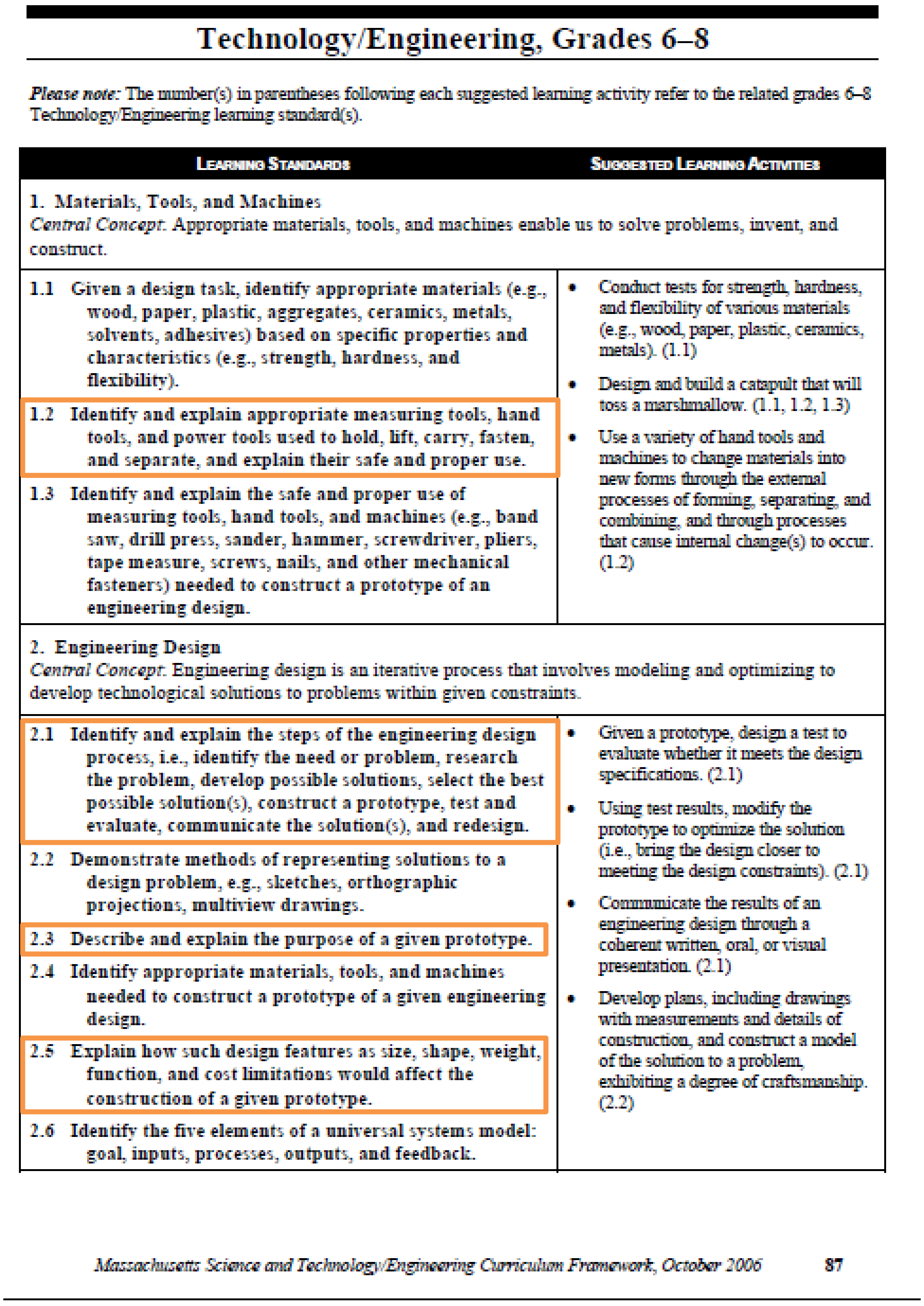
Physical Sciences (Chemistry and Physics), Grades 6–8

Learning Standard	Ideas for Developing Investigations and Learning Experiences
Properties of Matter	
1. Differentiate between weight and mass, recognizing that weight is the amount of gravitational pull on an object.	Determine the weight of a dense object in air and in water. Explain how the results are related to the different definitions of mass and weight.
2. Differentiate between volume and mass. Define density.	
3. Recognize that the measurement of volume and mass requires understanding of the sensitivity of measurement tools (e.g., rulers, graduated cylinders, balances) and knowledge and appropriate use of significant digits.	Calculate the volumes of regular objects from linear measurements. Measure the volumes of the same objects by displacement of water. Use the metric system. Discuss the accuracy limits of these procedures and how these limits explain any observed differences between the calculated volumes and the measured volumes.
4. Explain and give examples of how mass is conserved in a closed system.	Melt, dissolve, and precipitate various substances to observe examples of the conservation of mass.
Elements, Compounds, and Mixtures	
5. Recognize that there are more than 100 elements that combine in a multitude of ways to produce compounds that make up all of the living and nonliving things that we encounter.	Demonstrate with atomic models (e.g., ball and stick) how atoms can combine in a large number of ways. Explain why the number of combinations is large, but still limited. Also use the models to demonstrate the conservation of mass in the modeled chemical reactions.
6. Differentiate between an atom (the smallest unit of an element that maintains the characteristics of that element) and a molecule (the smallest unit of a compound that maintains the characteristics of that compound).	Use atomic models (or Lego blocks, assigning colors to various atoms) to build molecules of water, sodium chloride, carbon dioxide, ammonia, etc.
7. Give basic examples of elements and compounds.	Heat sugar in a crucible with an inverted funnel over it. Observe carbon residue and water vapor in the funnel as evidence of the breakdown of components. Continue heating the carbon residue to show that carbon residue does not decompose. Safety note: sugar melts at a very high temperature and can cause serious burns.
8. Differentiate between mixtures and pure substances.	



Physical Sciences (Chemistry and Physics), Grades 6–8

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Elements, Compounds, and Mixtures (cont.)	
9. Recognize that a substance (element or compound) has a melting point and a boiling point, both of which are independent of the amount of the sample.	
10. Differentiate between physical changes and chemical changes.	Demonstrate with molecular ball-and-stick models the physical change that converts liquid water into ice. Also demonstrate with molecular ball-and-stick models the chemical change that converts hydrogen peroxide into water and oxygen gas.
Motion of Objects	
11. Explain and give examples of how the motion of an object can be described by its position, direction of motion, and speed.	
12. Graph and interpret distance vs. time graphs for constant speed.	
Forms of Energy	
13. Differentiate between potential and kinetic energy. Identify situations where kinetic energy is transformed into potential energy and vice versa.	
Heat Energy	
14. Recognize that heat is a form of energy and that temperature change results from adding or taking away heat from a system.	
15. Explain the effect of heat on particle motion through a description of what happens to particles during a change in phase.	
16. Give examples of how heat moves in predictable ways, moving from warmer objects to cooler ones until they reach equilibrium.	Place a thermometer in a ball of clay and place this in an insulated cup filled with hot water. Record the temperature every minute. Then remove the thermometer and ball of clay and place them in an insulated cup of cold water that contains a second thermometer. Observe and record the changes in temperature on both thermometers. Explain the observations in terms of heat flow, including direction of heat flow and why it stops.

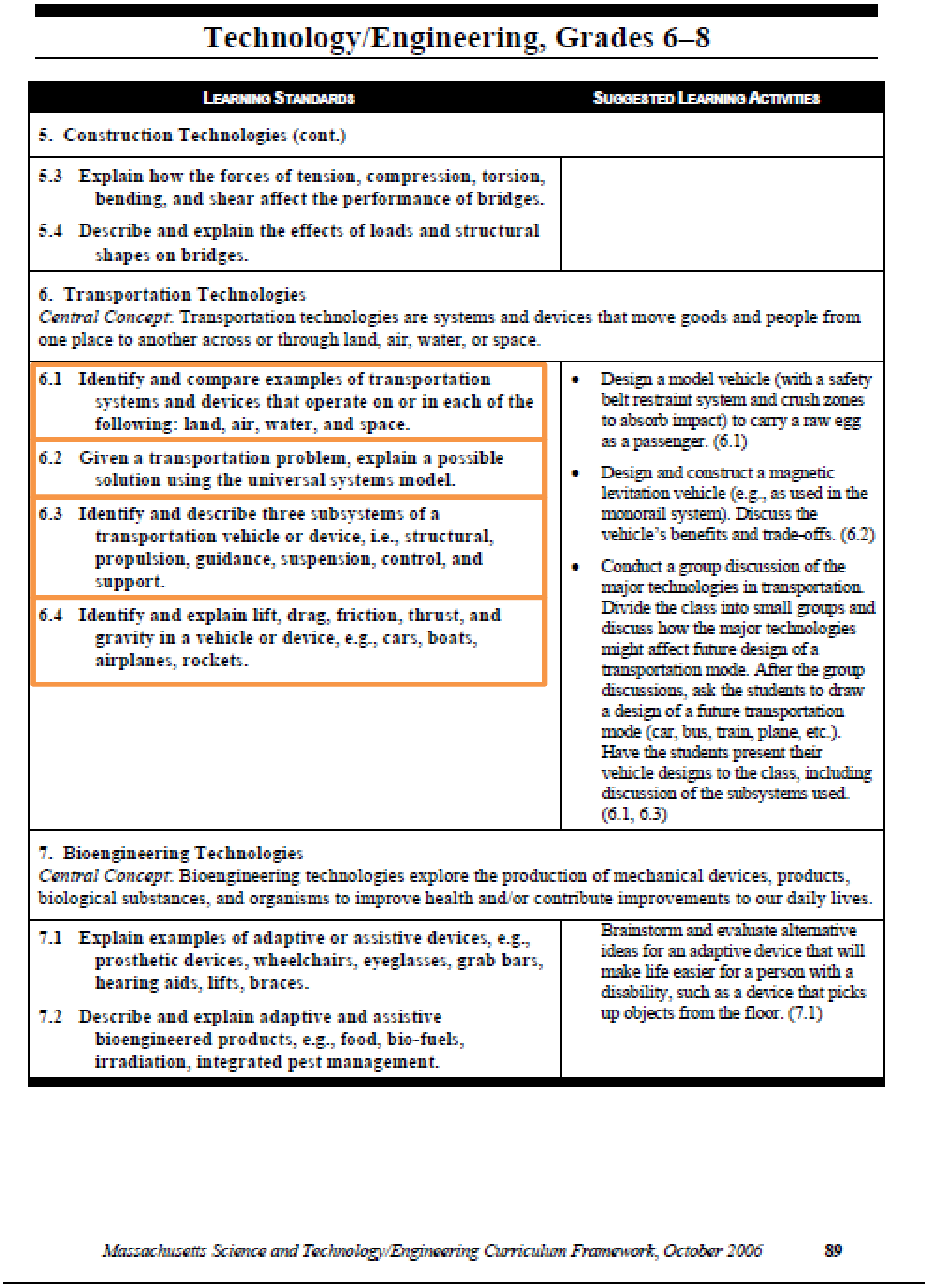


Technology/Engineering, Grades 6–8

Please note: The number(s) in parentheses following each suggested learning activity refer to the related grades 6–8 Technology/Engineering learning standard(s).

Learning Standards	Suggested Learning Activities
1. Materials, Tools, and Machines *Central Concept:* Appropriate materials, tools, and machines enable us to solve problems, invent, and construct.	
1.1 Given a design task, identify appropriate materials (e.g., wood, paper, plastic, aggregates, ceramics, metals, solvents, adhesives) based on specific properties and characteristics (e.g., strength, hardness, and flexibility). **1.2 Identify and explain appropriate measuring tools, hand tools, and power tools used to hold, lift, carry, fasten, and separate, and explain their safe and proper use.** **1.3 Identify and explain the safe and proper use of measuring tools, hand tools, and machines (e.g., band saw, drill press, sander, hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) needed to construct a prototype of an engineering design.**	- Conduct tests for strength, hardness, and flexibility of various materials (e.g., wood, paper, plastic, ceramics, metals). (1.1) - Design and build a catapult that will toss a marshmallow. (1.1, 1.2, 1.3) - Use a variety of hand tools and machines to change materials into new forms through the external processes of forming, separating, and combining, and through processes that cause internal change(s) to occur. (1.2)
2. Engineering Design *Central Concept:* Engineering design is an iterative process that involves modeling and optimizing to develop technological solutions to problems within given constraints.	
2.1 Identify and explain the steps of the engineering design process, i.e., identify the need or problem, research the problem, develop possible solutions, select the best possible solution(s), construct a prototype, test and evaluate, communicate the solution(s), and redesign. **2.2 Demonstrate methods of representing solutions to a design problem, e.g., sketches, orthographic projections, multiview drawings.** **2.3 Describe and explain the purpose of a given prototype.** **2.4 Identify appropriate materials, tools, and machines needed to construct a prototype of a given engineering design.** **2.5 Explain how such design features as size, shape, weight, function, and cost limitations would affect the construction of a given prototype.** **2.6 Identify the five elements of a universal systems model: goal, inputs, processes, outputs, and feedback.**	- Given a prototype, design a test to evaluate whether it meets the design specifications. (2.1) - Using test results, modify the prototype to optimize the solution (i.e., bring the design closer to meeting the design constraints). (2.1) - Communicate the results of an engineering design through a coherent written, oral, or visual presentation. (2.1) - Develop plans, including drawings with measurements and details of construction, and construct a model of the solution to a problem, exhibiting a degree of craftsmanship. (2.2)

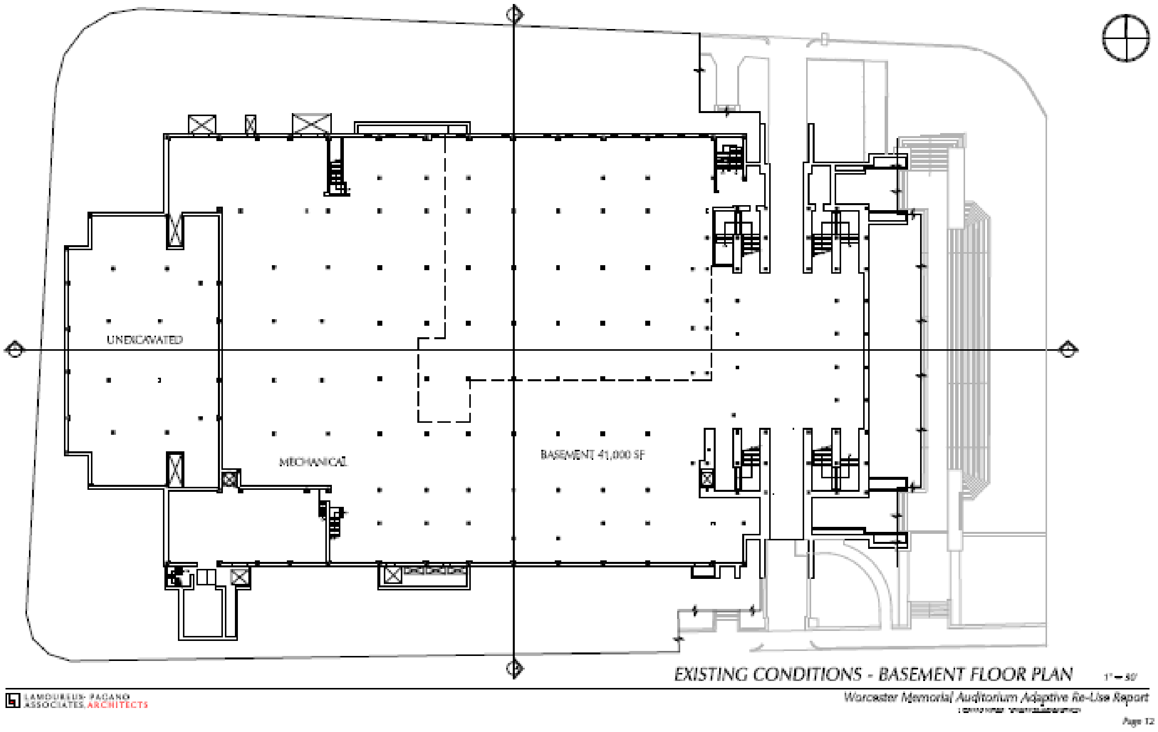
LEARNING STANDARDS	SUGGESTED LEARNING ACTIVITIES
3. Communication Technologies *Central Concept*: Ideas can be communicated though engineering drawings, written reports, and pictures.	
3.1 Identify and explain the components of a communication system, i.e., source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.	
3.2 Identify and explain the appropriate tools, machines, and electronic devices (e.g., drawing tools, computer-aided design, and cameras) used to produce and/or reproduce design solutions (e.g., engineering drawings, prototypes, and reports).	
3.3 Identify and compare communication technologies and systems, i.e., audio, visual, printed, and mass communication.	
3.4 Identify and explain how symbols and icons (e.g., international symbols and graphics) are used to communicate a message.	
4. Manufacturing Technologies *Central Concept*: Manufacturing is the process of converting raw materials (primary process) into physical goods (secondary process), involving multiple industrial processes (e.g., assembly, multiple stages of production, quality control).	
4.1 Describe and explain the manufacturing systems of custom and mass production.	
4.2 Explain and give examples of the impacts of interchangeable parts, components of mass-produced products, and the use of automation, e.g., robotics.	
4.3 Describe a manufacturing organization, e.g., corporate structure, research and development, production, marketing, quality control, distribution.	
4.4 Explain basic processes in manufacturing systems, e.g., cutting, shaping, assembling, joining, finishing, quality control, and safety.	
5. Construction Technologies *Central Concept*: Construction technology involves building structures in order to contain, shelter, manufacture, transport, communicate, and provide recreation.	
5.1 Describe and explain parts of a structure, e.g., foundation, flooring, decking, wall, roofing systems. **5.2 Identify and describe three major types of bridges (e.g., arch, beam, and suspension) and their appropriate uses (e.g., site, span, resources, and load).**	Design and construct a bridge following specified design criteria (e.g., size, materials used). Test the design for durability and structural stability. (5.3)



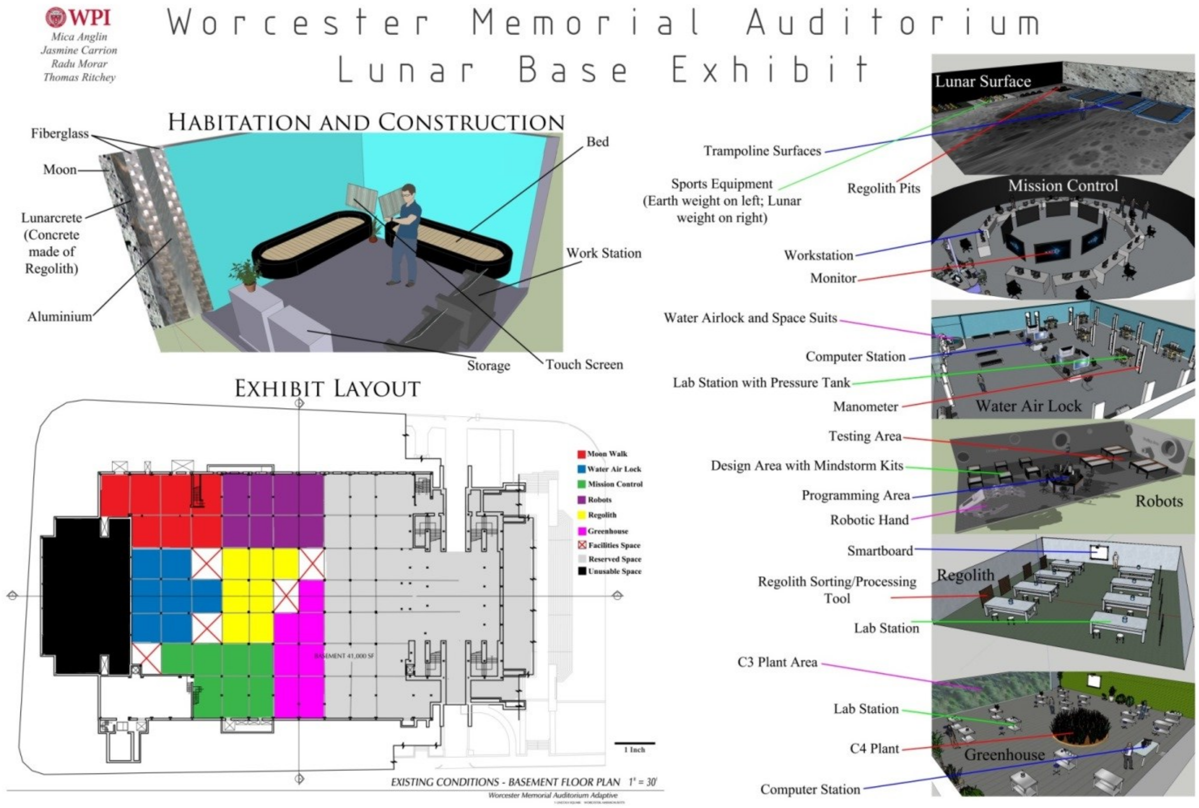
Technology/Engineering, Grades 6–8

LEARNING STANDARDS	SUGGESTED LEARNING ACTIVITIES
5. Construction Technologies (cont.)	
5.3 Explain how the forces of tension, compression, torsion, bending, and shear affect the performance of bridges. **5.4 Describe and explain the effects of loads and structural shapes on bridges.**	
6. Transportation Technologies *Central Concept*: Transportation technologies are systems and devices that move goods and people from one place to another across or through land, air, water, or space.	
6.1 Identify and compare examples of transportation systems and devices that operate on or in each of the following: land, air, water, and space. **6.2 Given a transportation problem, explain a possible solution using the universal systems model.** **6.3 Identify and describe three subsystems of a transportation vehicle or device, i.e., structural, propulsion, guidance, suspension, control, and support.** **6.4 Identify and explain lift, drag, friction, thrust, and gravity in a vehicle or device, e.g., cars, boats, airplanes, rockets.**	• Design a model vehicle (with a safety belt restraint system and crush zones to absorb impact) to carry a raw egg as a passenger. (6.1) • Design and construct a magnetic levitation vehicle (e.g., as used in the monorail system). Discuss the vehicle's benefits and trade-offs. (6.2) • Conduct a group discussion of the major technologies in transportation. Divide the class into small groups and discuss how the major technologies might affect future design of a transportation mode. After the group discussions, ask the students to draw a design of a future transportation mode (car, bus, train, plane, etc.). Have the students present their vehicle designs to the class, including discussion of the subsystems used. (6.1, 6.3)
7. Bioengineering Technologies *Central Concept*: Bioengineering technologies explore the production of mechanical devices, products, biological substances, and organisms to improve health and/or contribute improvements to our daily lives.	
7.1 Explain examples of adaptive or assistive devices, e.g., prosthetic devices, wheelchairs, eyeglasses, grab bars, hearing aids, lifts, braces. **7.2 Describe and explain adaptive and assistive bioengineered products, e.g., food, bio-fuels, irradiation, integrated pest management.**	Brainstorm and evaluate alternative ideas for an adaptive device that will make life easier for a person with a disability, such as a device that picks up objects from the floor. (7.1)

Floor Plan for Worcester Memorial Auditorium Basement



Lunar Base Exhibit Poster



WPI

Mica Anglin
Jasmine Carrion
Radu Morar
Thomas Ritchey

Worcester Memorial Auditorium
Lunar Base Exhibit

HABITATION AND CONSTRUCTION

Fiberglass
Moon
Lunarcrete (Concrete made of Regolith)
Aluminium
Bed
Work Station
Storage
Touch Screen

EXHIBIT LAYOUT

🟥 Moon Walk
🟦 Water Air Lock
🟩 Mission Control
🟪 Robots
🟨 Regolith
🟪 Greenhouse
☒ Facilities Space
⬜ Reserved Space
⬛ Unusable Space

BASEMENT 41,000 SF

1 Inch

EXISTING CONDITIONS - BASEMENT FLOOR PLAN 1' = 30'
Worcester Memorial Auditorium Adaptive

Lunar Surface
Trampoline Surfaces
Sports Equipment (Earth weight on left; Lunar weight on right)
Regolith Pits

Mission Control
Workstation
Monitor

Water Air Lock
Water Airlock and Space Suits
Computer Station
Lab Station with Pressure Tank
Manometer

Robots
Testing Area
Design Area with Mindstorm Kits
Programming Area
Robotic Hand

Regolith
Smartboard
Regolith Sorting/Processing Tool
Lab Station

Greenhouse
C3 Plant Area
Lab Station
C4 Plant
Computer Station

Lunar Base Exhibit 10 Page Supplementary Text

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Microsoft

Worcester, Massachusetts
USA

Table of Contents

Overall Exhibit Vision

The vision of this exhibit came from a marriage between the concept of a 2069 lunar base and desire to teach key concepts from the Massachusetts STEM curriculum in an innovative, hands-on, manner. The exhibit initially began with the premise of using different aspects of a lunar base as parts of the exhibit. While this provided for an excellent start, drastic modifications were needed to help the exhibit fall in line with the Massachusetts STEM curriculum. We felt that sticking closely to the curriculum was necessity in order to appeal to educators and aid in the improvement of standardized state test scores. In creating this vision, we followed the path of least resistance and attempted to create the environments used in the exhibit around the hands-on activities or experiments that we wanted to integrate into the exhibit. Another prominent goal in our overall vision was to create an immersive experience that would simulate being on a lunar base as much as possible. This was accomplished by designing the exhibit to look and feel like a moon base, from the minute that the students entered, to the minute that they left. Each room, or area, in the exhibit was modeled after a different part of a lunar base, with all of the activities taking place in these simulated environments. While creating all of this, we also focused on the need to make it attractive to students. The entire exhibit was created around the need for a visually stunning and tantalizing experience for the students. Special attention was paid to the design concepts of each portion of the exhibit as so to maximize the industrial and technologically advanced "look" that such a simulation exhibit should possess.

With the vast amount of information that the 5th through 8th grade STEM curriculums cover, we did not have the ability to cover everything. We tried to cover a breadth of topics that we felt were important in as much depth as possible given the constraints we were faced with. We ended up basing the exhibit on a fixed number of key concepts, realized through base activities; with the option for more activities and depth so as to create the most flexible and comprehensive exhibit possible.

Greenhouse Exhibit

The greenhouse is a critical portion of an actual lunar base. In terms of size, an actual lunar base greenhouse would take up a very large portion of the base. The greenhouse would be of paramount importance in recycling air as well as producing food and plants that would be used as raw materials. For the purpose of this exhibit, the greenhouse environment was created to be the same size as all of the other environments. While realism was a primary goal, there was no practical advantage to making the greenhouse larger than any of the other environments as it would only have detracted from the rest of the exhibit. We did, however, feel it was important for the greenhouse to include two distinct types of plants: C3 and C4. C3 and C4 are two of the three types of photosynthesis that exist. Since the focus of the greenhouse environment is photosynthesis we thought it would be fitting to have the C4 plants out in the open and the C3 plants in an enclosed location in which contained two times the normal amount of carbon dioxide. This is more realistic as C3 plants thrive in carbon dioxide rich environments and they would be stored in such conditions in order for them to reach their full potential. For the exhibit, this could be done by storing them in a portion of the greenhouse enclosed by safety glass. The other possibility is to project the image of such an environment on a screen behind safety glass. Either of these would be acceptable ways of realizing such a simulation.

While vastly scaled down in size to fit in with the other parts of the exhibit, the greenhouse is still filled with a token amount of plants to enhance the simulation without creating unnecessary work. Inside the greenhouse, there are workstations where the students will be able to complete an activity involving testing for starch in plants. This introduces the students to the concept of photosynthesis, if it is not already prior knowledge, including the fact that there are three types, although they are only exposed to C3 and C4. After the introduction, they perform the activity on two plants, one that was kept in darkness for at least 24 hour and one that was not. The plant that was kept in darkness will not show signs of starch, a byproduct of photosynthesis. The plant that was kept in normal light, on the other hand, will show a sign of starch, which indicates that photosynthesis took place. This experiment is done to reinforce the fact that producer plants (plants which contain chlorophyll) use energy from sunlight to create sugar and oxygen from carbon dioxide and water, a process which we know as photosynthesis. The plants must contain chlorophyll to do this and thus the process takes place in the green "leafy" portions of the plant. The students will also be taught about how the plants are used to "recycle" air in the greenhouse by turning the carbon dioxide that humans breathe out to oxygen which humans need to breathe in.

Mission Control Exhibit

The mission control exhibit is designed to incorporate a lot of the pertinent Lunar Base Exhibit information and imagery that did not fit in elsewhere. The mission control on the base is used as a central command center for communication, controlling robots, and controlling essential base functions such as life support. This room has been modeled as a circular room with computer workstations arranged in the shape of a torus (donut). This strays from the motion picture concept of straight rows of workstations as it allows for better communication. The computer workstations will face the center of the torus. Inside the center are large monitors arranged, yet again, in the shape of a torus. This allows for every workstation to clearly see at least one of the monitors. This room is used to interactively develop moon base concepts involving radiation, communication, and transportation. These concepts aid students in learning about heat transfer, basic physics (forces on a body on earth, in space, and on the moon), and the inner workings of basic engineering technologies (transmitters, receivers, etc.). The students watch videos that explain and teach them these concepts. Once they've been exposed to them, they play interactive games based on one or more of the concepts. The scope of the majority of the interactive games is teamwork, communication, and quick decision making. The games are based around the concept of identifying problems, relaying the problems to the rest of mission control, and making swift and accurate decisions as a team/whole to correct the problems.

Moon Walk Exhibit

The moon walk exhibit is created in order to simulate the surface of the moon as well as the water airlock that is used to travel from the lunar surface into the base while maintaining a habitable pressure and oxygen level inside the base. This exhibit features a lunar surface and an airlock room. The floor of the lunar surface is made to appear as if it is covered in regolith, lunar soil, and the walls are made to simulate the lunar landscape. A portion of the surface of this room is a light trampoline surface. This is used to simulate the weightlessness that would be experienced on the moon while the students walk or jump on it. This is to teach the students about the difference between weight and mass, and how weight is mass multiplied by the local acceleration due to gravity. Another portion of this room has two sets of identical sports balls on separate tables. One set weighs six times the weight of the other set based on the different acceleration due to gravity between the moon and earth. This is to allow the students to compare and contrast the properties of things on earth vs the moon by picking them up and tossing them back and forth. The airlock room is made to look like it's submerged in water. In the room are lab stations with manometers, pressure tanks, and various gages. They are used to introduce the concept of density via an experiment where students use the tank pressure to control the water level in the manometer. This is tested and explained using a simplified version of Bernoulli's equation. This is also used to explain how the water airlock works as it is essentially a large U-tube manometer used to regulate two different pressures via a height differential. The students use the theory to engage in a contest as to which team (of 3 or 4) can operate the manometer and its equipment most competently.

Regolith Exhibit

In this exhibit, students will be asked to sort lunar regolith. A series of different color and size wax balls will be used to represent regolith. Each ball size and color will represent a different element found in regolith. The exhibit will be set up with a large pit where the regolith will be stored. There will also be six work stations, with peg boards, for the students to work at. There will be up to five children in each group with one group for each work station. The regolith storage pit will be in the middle of the room, with the work stations on both sides, and an instructional area that will be in the front of the room. There will also be supplementary regolith pits on the lunar surface. The exhibit will have three main parts. The first part is a basic introduction to what regolith is and how it could be used on a moon base. The students will also be asked questions about the chemical properties of the regolith, including whether it is a mixture or pure substance, and how different elements can combine to form compounds. These questions help students learn about elements, compounds, and mixtures which satisfies learning standards from the physical sciences section of the curriculum. In the next step, the students begin to interact with the regolith. The students will be given a peg board to help separate the regolith. However, the board's setup will need to be created by the students. The board will have a series of different holes where pegs can be placed to help guide the balls to their designated sections, thus separating them so each element (ball) falls only into the right section. The students would be given about 20 minutes to build and test their tool. In the final step, the students take the wax and melt it down. They will then pour the wax into molds, which when submerged into cold water will harden. This process gives an example of material processing via heat, which is a popular method of extracting elements from compounds.

Robots Exhibit

The exhibit's goal is to encourage students to build and program a lunar robot that could traverse terrain and collect different color balls (which represent regolith). The exhibit will be split into three parts, first part is to build the robot, the second will be to program the robot, and the last part involves testing it. The Maximum amount of students is 24, the experience will last roughly 1 hour and twenty minutes; students will be divided into groups of four. The Massachusetts STEM curriculum will be used as a guide line for the robotics exhibit; focusing on manufacturing technologies and transport technology. In the design area, each group will be given a Lego Mindstorm kit which has a variety of Lego pieces such as large motors, medium motor, an ultrasonic sensor, a pair of touch sensors, a gyro sensor and a color sensor. The computers in the programming area run off software that is included in the Mindstorm kits. The program is very easy to use; it only requires that students drag and drop command symbols to program their robot. As the students finish programming, they move into the testing area where there is a race between two teams to see which team has the most accurate and efficient robot. Teams will face a terrain that varies in difficulty as the robots reach the far end of the course. As the students' robots move along the course, the surface changes from a slick surface, representing ice, to a granular floor, representing loose rock. Towards the end of the course, the terrain will pitch upward and then back down in order to represent a crater.

Lunar Life Simulation

The simulation of being on the moon will be consistent throughout the exhibit. When students first enter, they will watch a short video of a spacecraft mission to the moon. As the schoolchildren experience the different exhibits, they will be made to feel like they are on the moon through various hands-on activities. The air lock will give the students the feeling of being submerged in water and the lunar surface will mimic the surface of the moon. As they wander towards the mission control they will see large flat screen monitors, displaying the latest robot models. Students will soon learn about the effects of space on plant life upon seeing the lush plants in the greenhouse. Keeping the moon in mind, the last three exhibits all explore the uses and processing of regolith. A perfect example is the regolith-separation exhibit, where students will learn about the materials in regolith and how they differ from one another. In addition to regolith, the lunar surface exhibit also portrays gravity's effect on the perceived "weight" of an object. Most exciting of all, the robotics exhibit will inspire creativity with the use of the latest Lego Mindstorm kits. During the field trip, the students will eat in designated exhibits so as to not "break" the lunar simulation. The bathrooms will use energy saving facilities, which use motion sensors and thermal sensing. The thermal sensing will keep the water at a pleasant temperature. All of this ensures that the lunar base experience is immersive and uninterrupted from start to finish.

Lunar Habitation Concept

The living quarters for the lunar base crew would be large enough to not seem cramped, but small enough to allow as much room as possible to be utilized for the base's primary mission at the time. In the exhibit, the living quarters would be viewed digitally from mission control. This is mainly to save space for the other environments as the habitation concept was not selected as one which would be used to convey any of our key educational topics. Habitation, however, would still be discussed and used to show the different layers of material from which the base is constructed. The base is constructed from multiple layers of Lunarcrete (concrete made from regolith), fiberglass, aluminum (which is used to transfer electricity), and more fiberglass to insulate the aluminum. The base runs 24 hour a day, but at any point roughly 1/3 of the crew is asleep. The crew works in six-hour shifts at least 12 hours off after each shift. The minimum amount of space that each person would have for habitation is 15 square feet; however, it is possible that there would be more depending on base size and design. Most rooms would be double rooms with two beds if it was necessary to save space and include as many amenities such as computers, reading lights, ventilation, etc. The rooms would also feature clever storage options to maximize storage while using as much "dead" space as possible.

Overall Exhibit Model

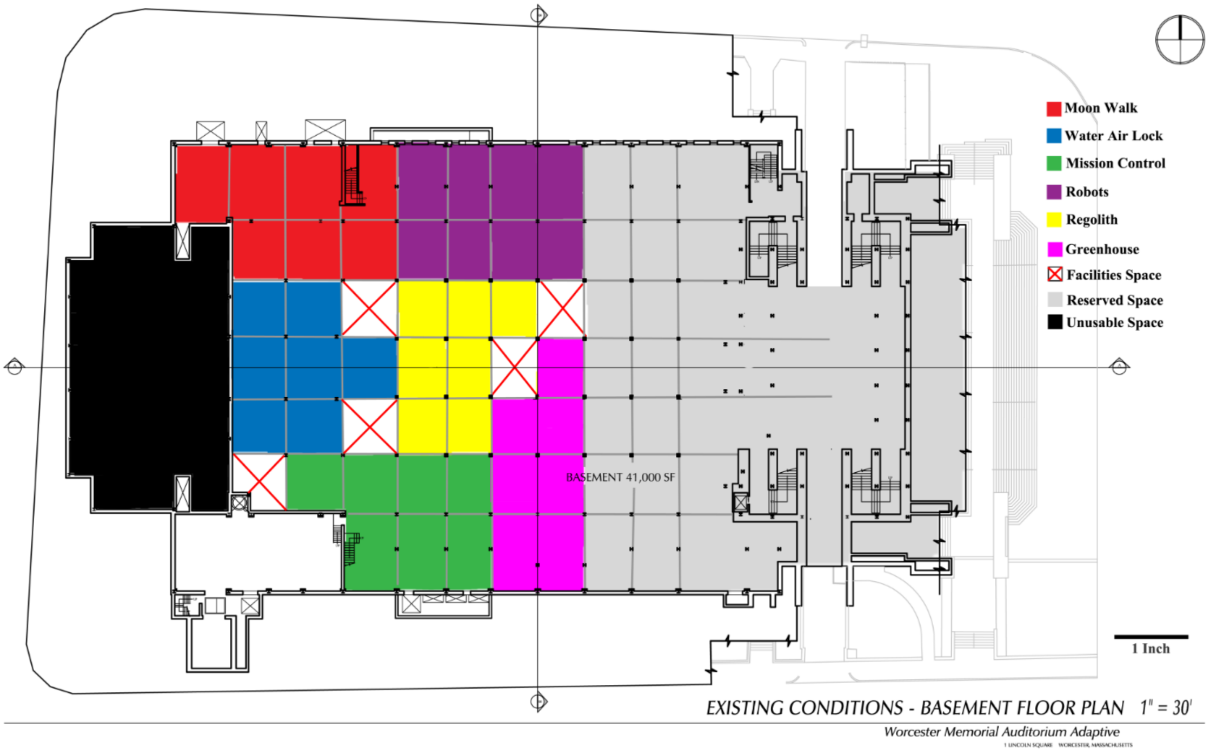
The overall model of our lunar base exhibit was one in which students would visit the exhibit once, at any point in time, during their 5th through 8th grade curriculum. This was a deviation from the other method which proposed that the exhibit would be visited yearly by the same classes and would evolve as the students progressed through their 5th through 8th grade curriculum. Initially, we were not exposed to the idea of an exhibit that would evolve as students progressed through our target grade levels, but when confronted with the idea we viewed it as impractical and too complicated to integrate into our Lunar Base Exhibit. The idea that the students would visit once at any point allowed us to focus in on some key topics that are covered, more or less, in each year of the 5th through 8th grade curriculums. These topics, which we considered to be topics of importance in STEM (Science Technology Engineering and Mathematics), would be covered in various ways and in varying amounts of depth to fit the background knowledge and level of each grade and class that was brought to the exhibit. The sub-exhibits would feature at least one base hands-on learning activity/experiment for each part: the Moon Walk, Mission Control, Regolith, Greenhouse, and Robots. They would also feature additional activities/experiments, in-depth explanations, or corollaries based on need and available time. The exhibit team felt that this would provide a more focused approach towards teaching the key Stem Topics since it allowed for the improvement and eventual perfection of the exhibit, rather than the continuing need to create new and diverse sub-exhibits to fit the grade that it was focusing on each year. This would also allow more diversity in terms of visitors as it did not focus on bringing back local schools each year. Instead, the focus would be to attract schools from as far away as feasible, relying on the fact that visiting once at any time between 5th through 8th grade made this exhibit more attractive, flexible, and convenient for almost any school district.

Building Constraints and Exhibit Logistics

The Moon Base exhibit will be housed in the Worcester Memorial Auditorium. The auditorium was originally designed as a memorial to those who died in World War I. The building includes a Memorial Hall and lobby, the grand auditorium, the Little Theater, and an expansive basement area. The building has not had a very stable or permanent purpose for many years, but the building is in relatively decent shape considering it was built in 1933. The biggest repairs would involve the electrical and mechanical systems. Besides this, most of the necessary repairs would be cosmetic. The entrances also need to be updated, as many are not handicap accessible. This would be a large undertaking and the cost would need to be evaluated before committing to this space completely. The schoolchildren would need to be brought in buses, and they would be dropped off at the back of the auditorium. Due to the zoning constraints of the building, there can't be a food service, restaurant, in the building. The Lunar Base exhibit, which would share space with the Mars exhibit, would be located in the basement, occupying roughly half the available space. We would also utilize the little theater, for a greeting and an introductory presentation. The basement has 41,000 square feet of available space, when split with the Mars exhibit, the Moon Base exhibit will contain roughly 20,500 square feet of usable space. This space will easily be able to hold the approximately 150 students and chaperones that would be expected to view the exhibit at one time. Unfortunately, the building only contains one truly usable floor for the exhibit, while a moon base would comprise of many different floors. To overcome this limitation, the use of faux elevators could be used to portray changing floors.

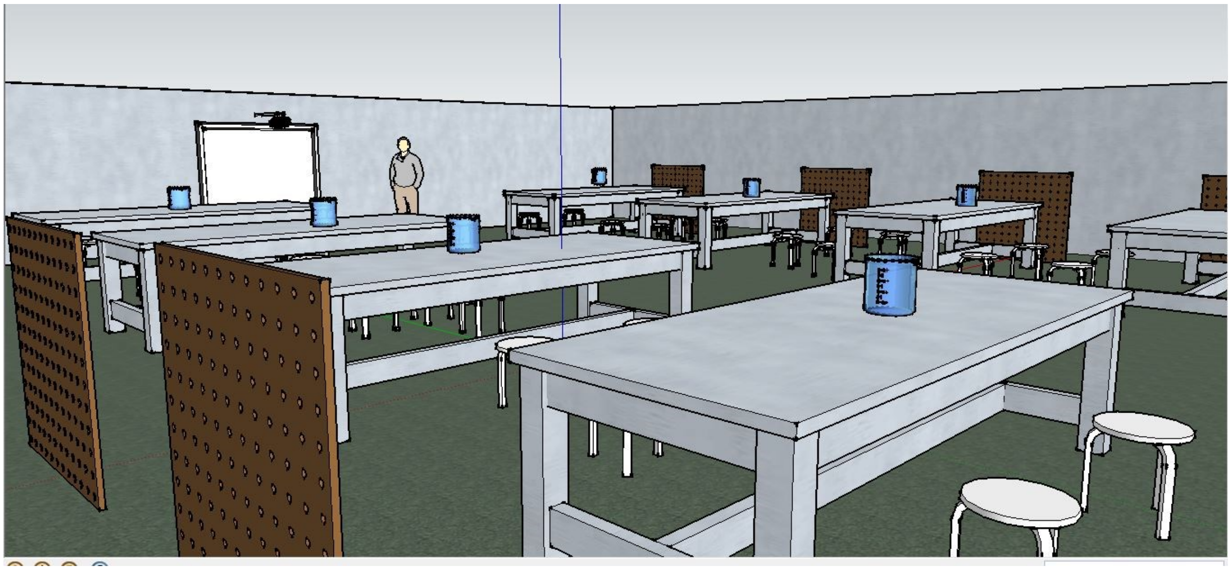
Due to the fact that this exhibit would require most of a school day to complete, students would have to eat lunch at the exhibit. Lunch would have to be a bagged lunch that each student brought as zoning laws prohibit food from being served at the auditorium. Keeping in line with the need to simulate a lunar base, the students would most likely eat their lunch in designated exhibit environments or rooms as space limitations prevent us from creating a "base cafeteria". Another need would be a rest area, or employees lounge area for the presenters and exhibit employees to take any breaks they need. Bathrooms would also be one of the largest concerns. Since the space does not contain many, additional bathrooms would need to be added as would adequate plumbing for them.

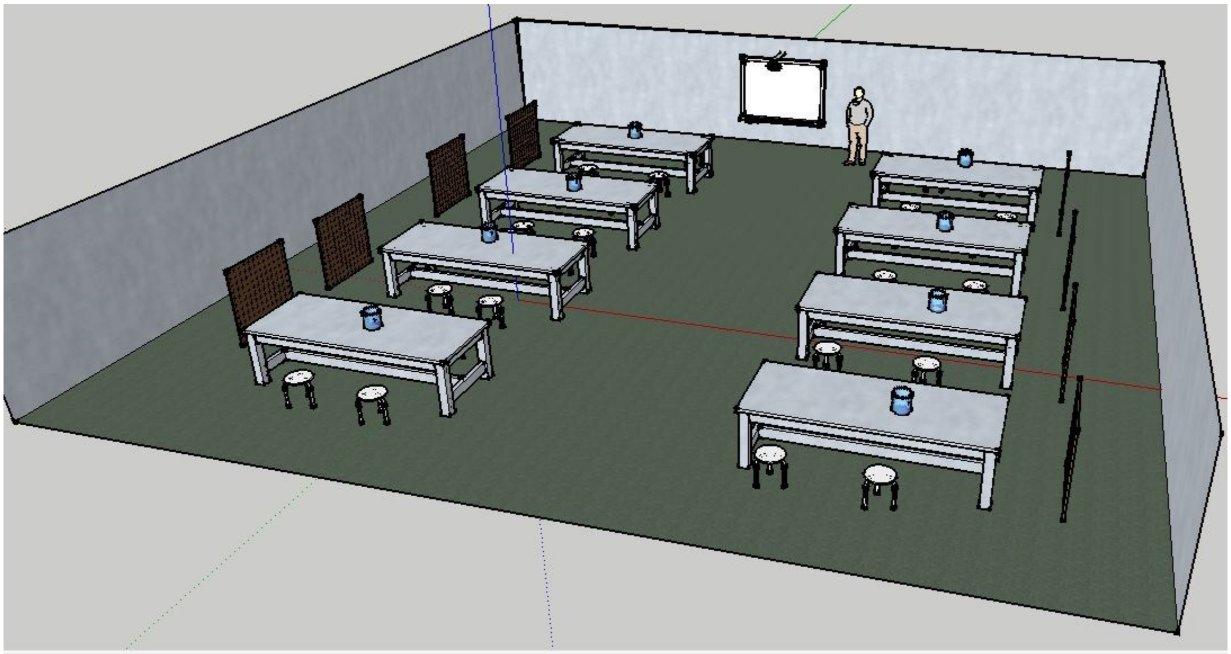
Two Dimensional Exhibit Layout in Basement of Worcester Memorial Auditorium



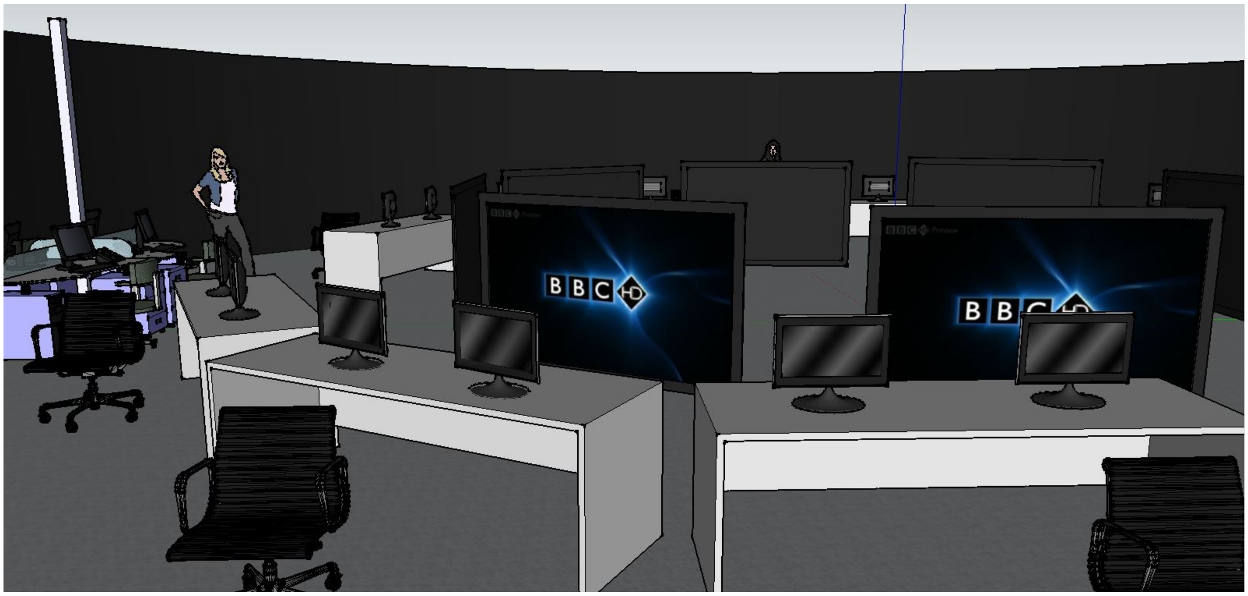
3D Exhibit Design Concepts

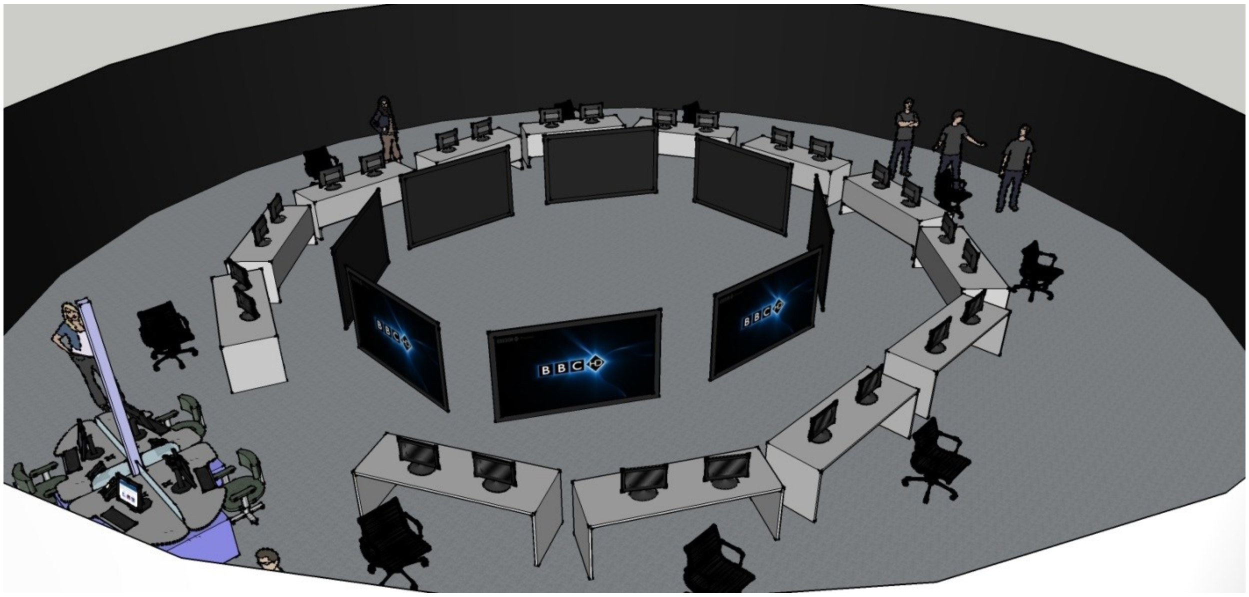
Regolith Imagery



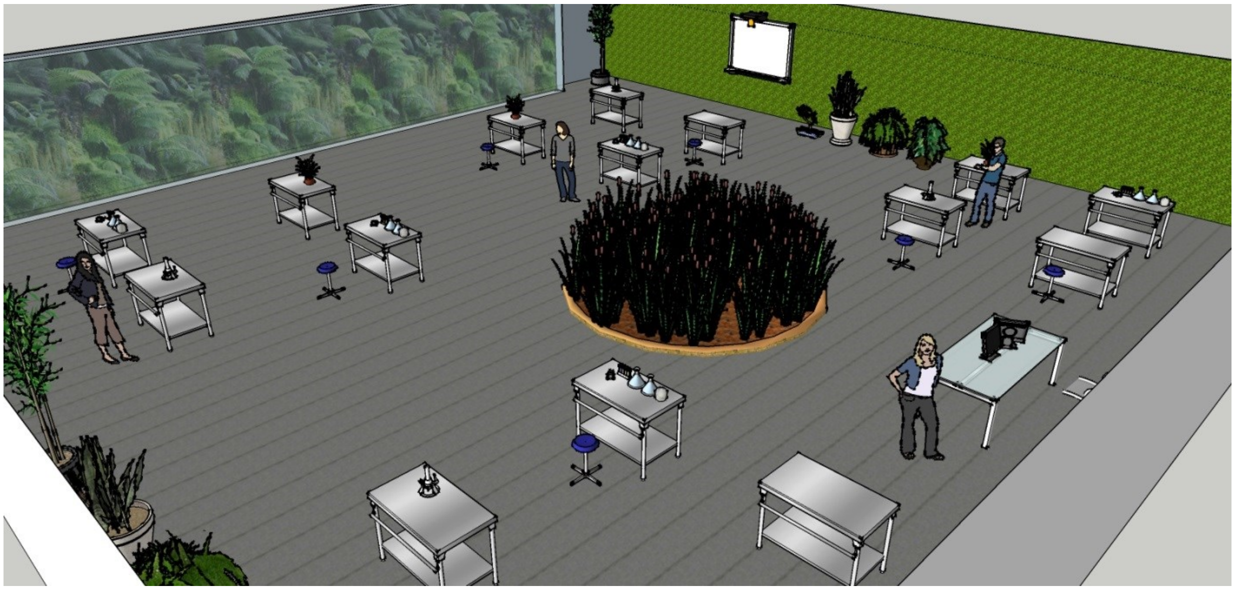


Mission Control Imagery





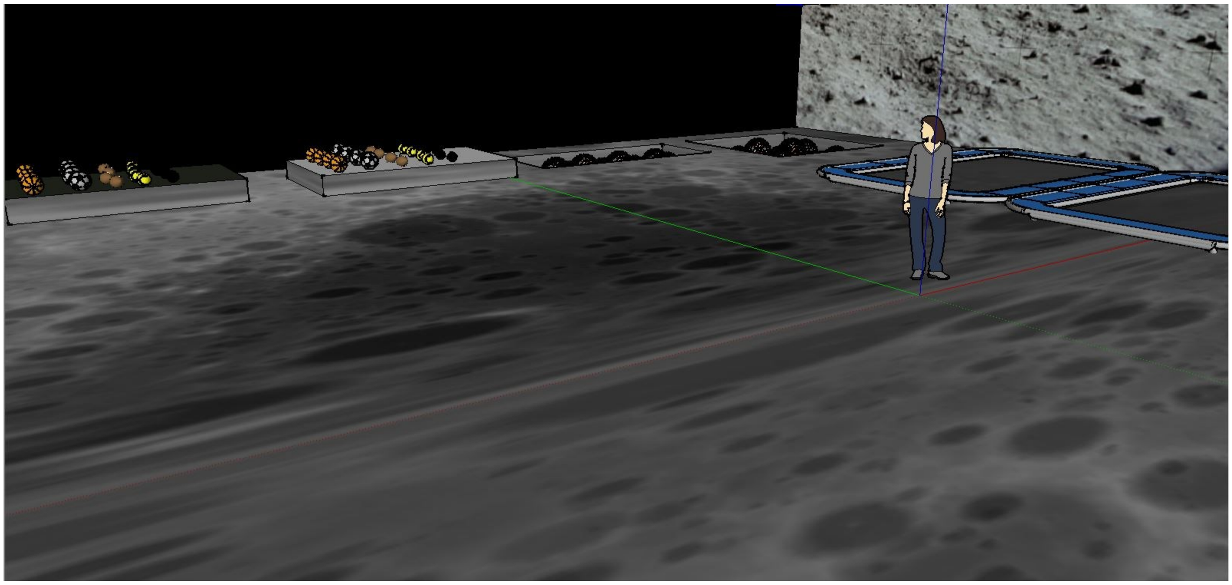
Greenhouse Imagery

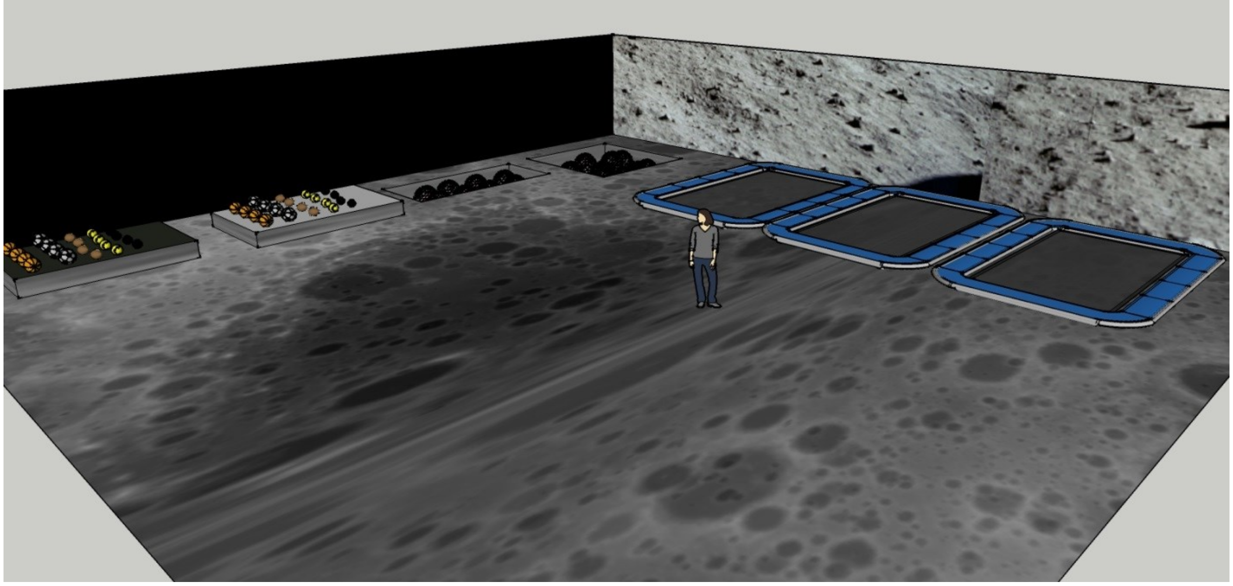


Robots Imagery

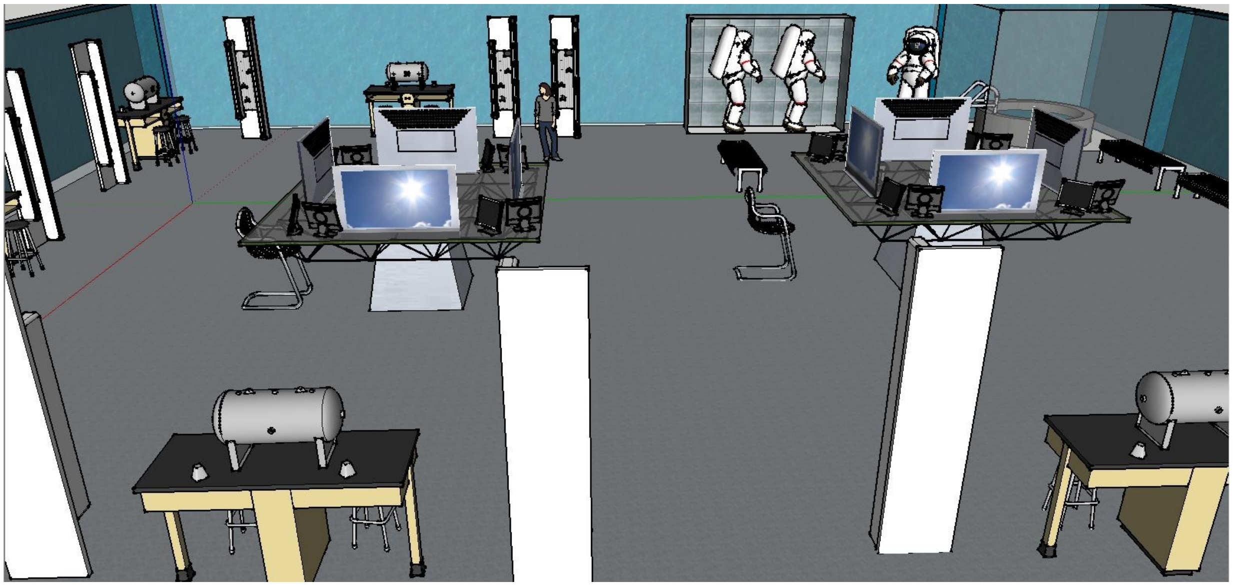
Moon Walk Imagery

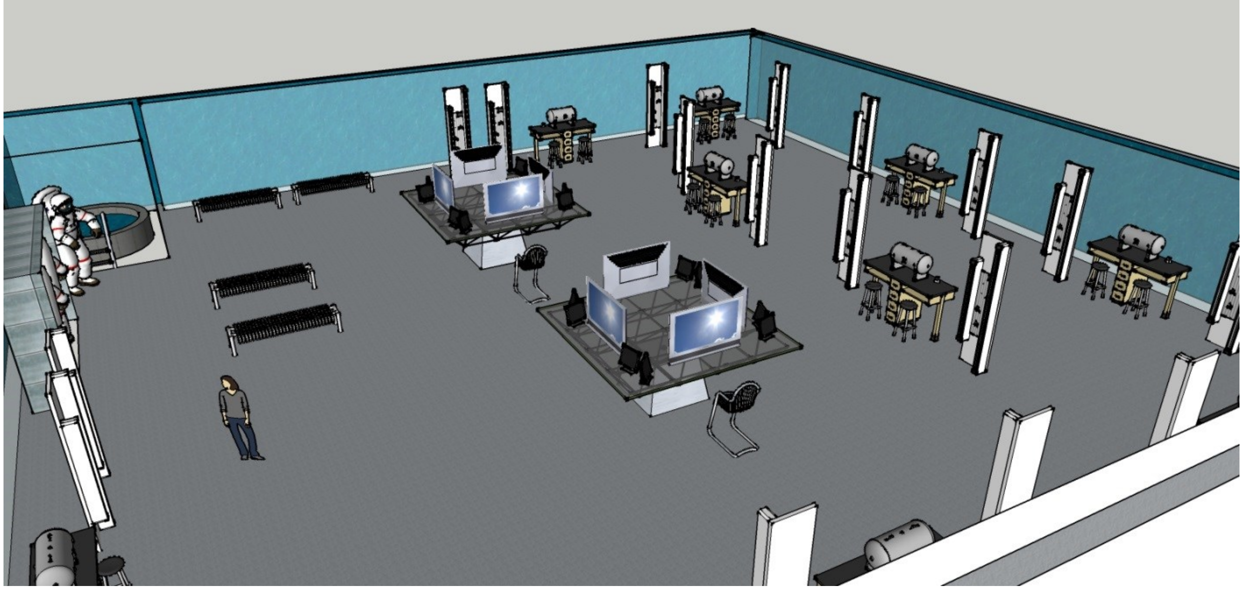
Lunar Surface





Water Air-Lock





Habitation Imagery