CASIS National Design Challenge

Vermicomposting in a Microgravity Environment

Supervising Teachers:
Shanna Atzmiller
Jesse Swift

Student Contributors:
Alexa VanSchaardenburg
John Weiler
Anissa Shull
Linus Woodard

Participants of Project
Bell Middle School Class of 2015
Bell Middle School
Golden, Colorado

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1.0 Problem Statement

The world's space agencies are investigating the crucial need for a natural way to eliminate biodegradable waste on the International Space Station. Since 1998, crew members have been sending their waste back to Earth to be processed. Continually sending waste back down on unmanned spacecrafts is an inefficient use of resources because it costs extra time and money. The current practice is also harmful to the environment because a majority of the waste is purposely burned up within the atmosphere during re-entry. One of the methods being researched for a solution is vermicomposting, which is the process of worms breaking down biodegradable waste and creating fertilizer. Vermicomposting is an alternative and necessary solution because 85% of the waste that the crew members produce is already biodegradable. By solving this issue, we will accomplish the reduction of waste produced and thusly removed from the ISS. This will eliminate environmental harm, provide more resources and allow for the reuse of products for future space exploration.

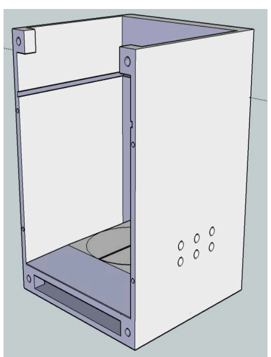
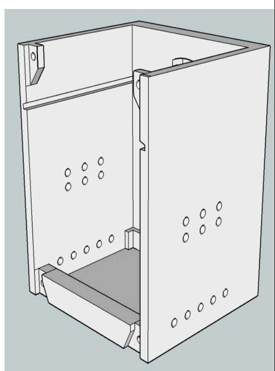
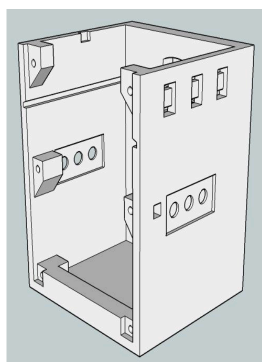
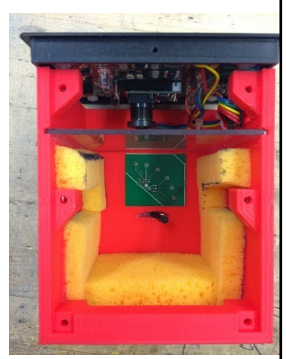
2.0 Design

2.1 Test Chamber

Initial Concept:

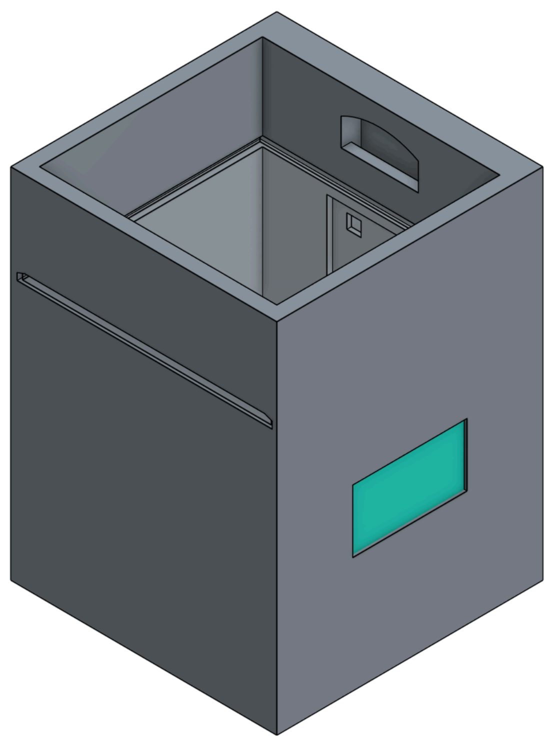
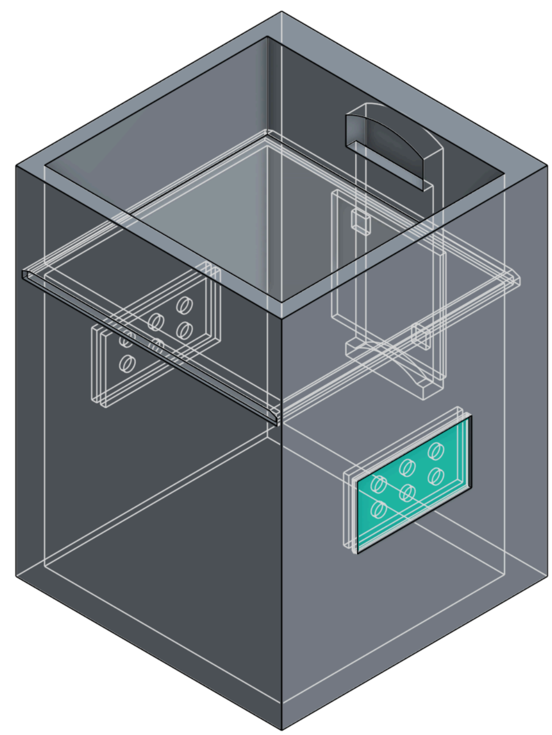
Simplistic design prevailed amidst many other ideas, such as a door and servo operated hatch. Reducing the number of moving parts to decreased the probability of experimental error in the test chamber. This allowed for less production time in creating the test chamber. Multiple layers of waterproofing (Silicone, 3d printed walls) were present to isolate the experiment to the NanoLab 1.5 AU, not only keeping the experiment from the ISS, but, also visa versa; reducing as many external variables that could have altered the experiment as possible. As depicted below, the primary iteration of the test chamber has a large variation of features when compared to the launched test chamber, primarily door location, in which- to reduce complexity further- the door was moved to the top of the chamber, implementing the lexan (which was already present) to serve as the door.

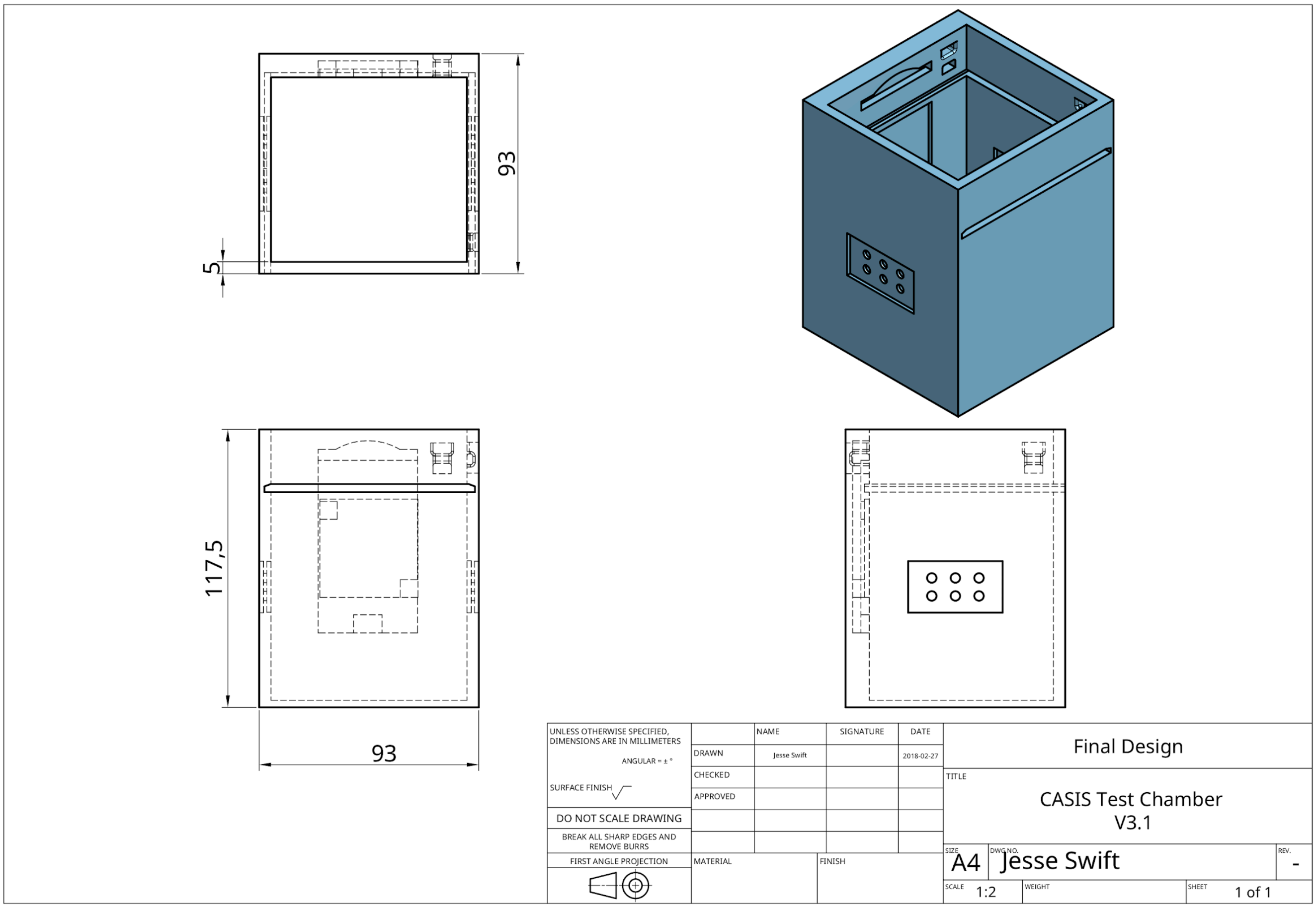
The test chamber was printed with PLA material on a Lulzbot Taz 4 printer at 20% infill. The students designed the test chamber in CAD at first in Sketchup and later in OnShape a new, cloud based CAD software. Link to final design here. https://cad.onshape.com/documents/c4456014f87e48119c3116e3/w/4434f4081c7e46a6b65d48b0/e/c85e8e5029fb439cb8971089

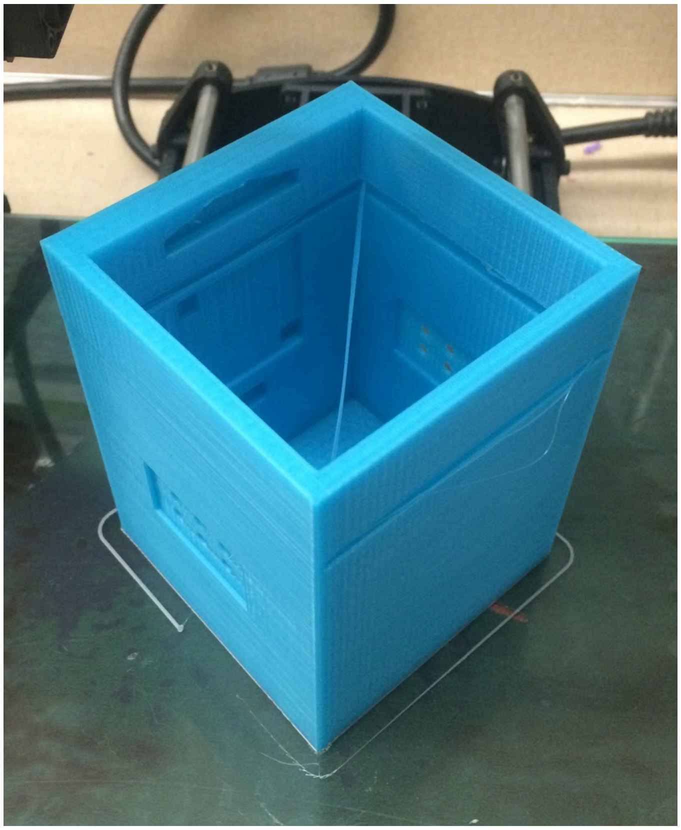
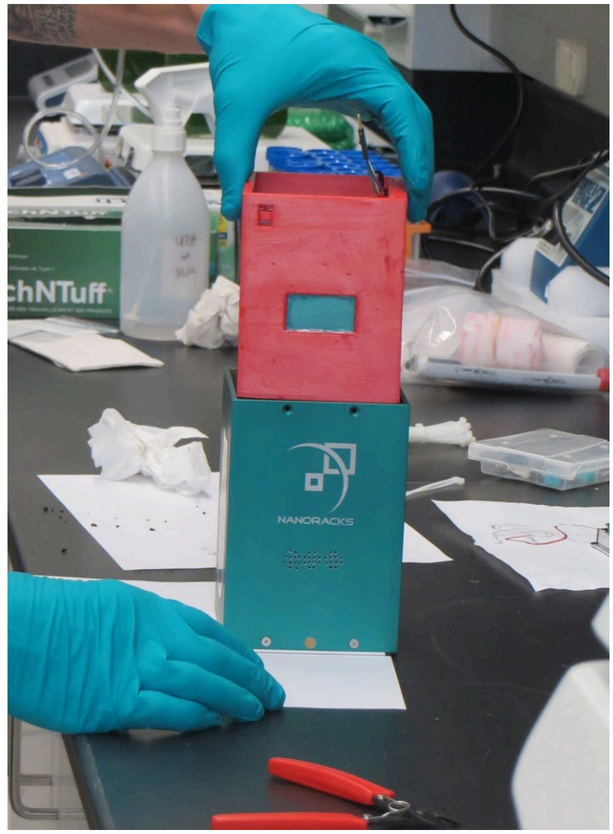
Test Chamber Evolution - For CRS-7 Flight				
				
Module V1.1- separate worm chamber with no cold stow	Module V2.1 - worms are placed in chamber for cold stow	Module V2.2 - changes made to ventilation and added zip-tie ports	Module V2.3 - front view with NESI board, sensors and sponges installed	Model 3.1 - packed for Ground Based testing

Final Design

For the CRS-11 launch, modifications were made to the design of test chamber. Prior to the CRS-7 launch, we were informed there were small leaks detected by NANORACKS after hand off. To prevent water leaks in the future, the decision was made to remove the door panel and o-ring channel. This new design removed the need for six threaded bolts, six threaded nuts, o-ring material and a seperate printed "door" piece. Again, simplicity was better than complexity.

Test Chamber - Final CAD Design	
	
Module V3.1 - Removable of external door	Module V3.1 - Hidden line view

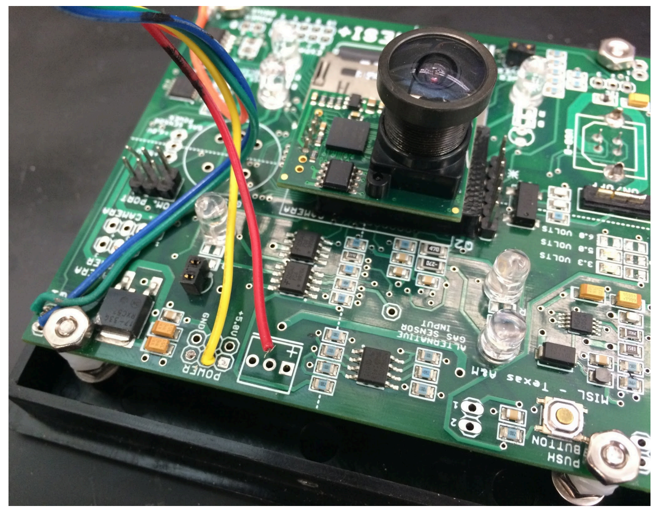

93
5
117,5
93
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS
ANGULAR = ± °
SURFACE FINISH
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
FIRST ANGLE PROJECTION
NAME
SIGNATURE
DATE
DRAWN
Jesse Swift
2018-02-27
CHECKED
APPROVED
MATERIAL
FINISH
Final Design
TITLE
CASIS Test Chamber V3.1
SIZE
A4
DWG NO.
Jesse Swift
REV.
-
SCALE
1:2
WEIGHT
SHEET
1 of 1

Test Chamber - Final 3D Printed Design	
	
Module V3.1 - Freshly printed on 3D printer	Module V3.1 - Insertion into Nanolab at KSC Lifesciences Center May 29, 2017

2.2 Hardware

Micro Controller

If the testing chamber acted as the heart of the experiment, the NESI+ board certainly was the brain. The camera module, temperature and moisture sensors were attached to the NESI+ board. From the initial introduction to the NESI+ board and coding, it was immediately determined that the simplest code would, again, be the most suitable for the challenge at hand. As was originally planned, one picture, along with one reading from each of the sensors would be taken three times, every 6 hours of everyday the experiment was running.

NESI+ Microcontroller	
	
NESI+ board and Nanolab - Photo take July 2014 at Wings Over Rockies in Aurora, CO.	Close up photo of connector wires and camera module attached to NESI+ board.

As show below, the code for taking photo was very simple. This code was integrated into the code for recording the temperature and moisture at the same time the photos were taken.

NESI+ Code

main-my_pix_on_button.c

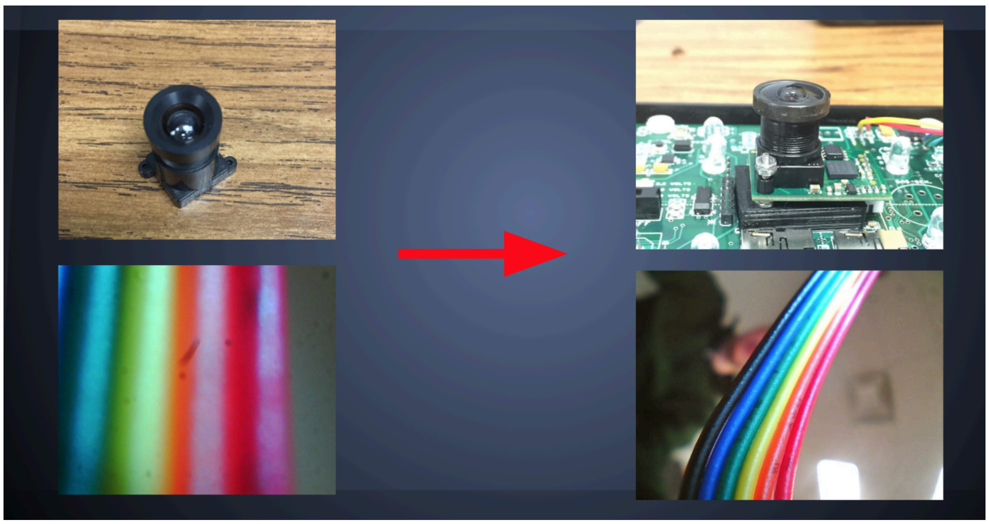
```
/*  This program takes a pix and stores it when the button is pushed.
 * REMEMBER  -- jumper JP15 pins 1 and 2 for software control of camera
 * power and pins 2 and 3 for always on
*/

#include <nesi.h>


int main(void)
{

    nesi.init();            // Initializes NESI modules


    //prepare the usb connectivity
    usb.connect();
    wait(1000);

    while(1)
    {

    if (button.getStroke())
        {
        // disable button keystroke detection
        button.disableStroke();

        // disconnect USB SD card (in case routine writes to SD memory)
        usb.eject();

        // take a picture
        camera.getPix("my_picture.jpg");

        // reconnect USB SD card (to read files)
        usb.connect();

        // enable button keystroke detection
        button.enableStroke();

        //flash LED once
        // illuminate Red LED
        ledR.dutycycle(50);

        wait(1000);

        // lights off
        ledR.dutycycle(0);
        }

    }

    return 0;
}
```

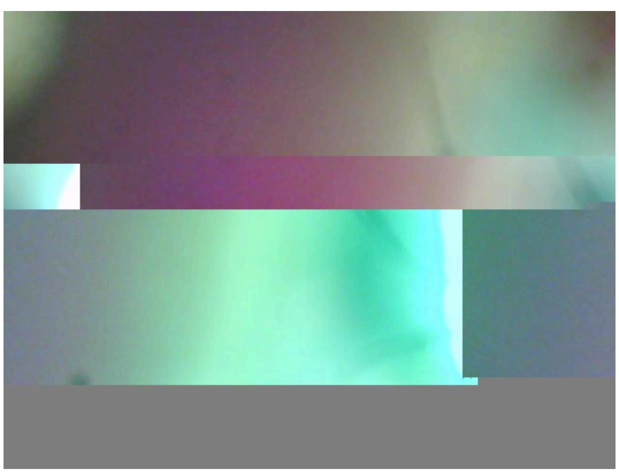
Screenshot of code for camera to take photo, turn on LED and record image to SD card.

Aside from minor code revisions, the major change the NESI+ and code faced was the revision of time in between readings. Initially, the 3 readings per hour took place milliseconds apart. As was later determined, the short time between the readings lead to the gathered data being corrupted (Mentioned under Camera). Finally, the time between data gathering was increased dramatically to 60 second time intervals, thus allowing for the NESI+ board to compute the gathered data and produce accurate measurements and readings. While the moisture sensor and camera worked with only a few, easily fixable flaws, the temperature sensor proved to be a source of strife. It consistently overheated well into the final days of work. It was finally determined that between poor heat transfer and a possible short, the ultra high readings initially faced reflected a mechanical, and not experimental failure.

Camera Module

The camera module proved to be very sensitive to adjustment, with the lense change and increased picture interval becoming paramount in order to capture clear and insightful pictures. Moreover, a camera spacer was fabricated in order to provide a level of security for the otherwise flimsy camera mounting point, thus, during launch, the camera module was held in place, once again, simplicity proved to be a theme of the experiment, for it only took a shim to solve a possibly catastrophic flaw; a lack of pictures due to a detached camera module. The aforementioned lense change provided a drastic benefit to picture quality, with the switch to the macro lense increasing detail and focus level of the worms and dirt.

Camera module

The difference of focal points between each camera lens.

NESI+ - Camera Images	
	
Corrupted Image due to Interval Time	Image showing worm composting during ground based test.

NESI+ Camera Images - CRS-11 Flight images	

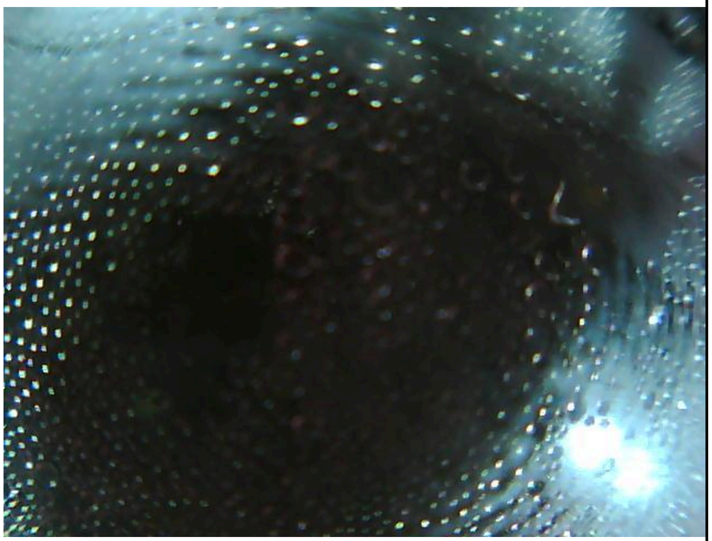
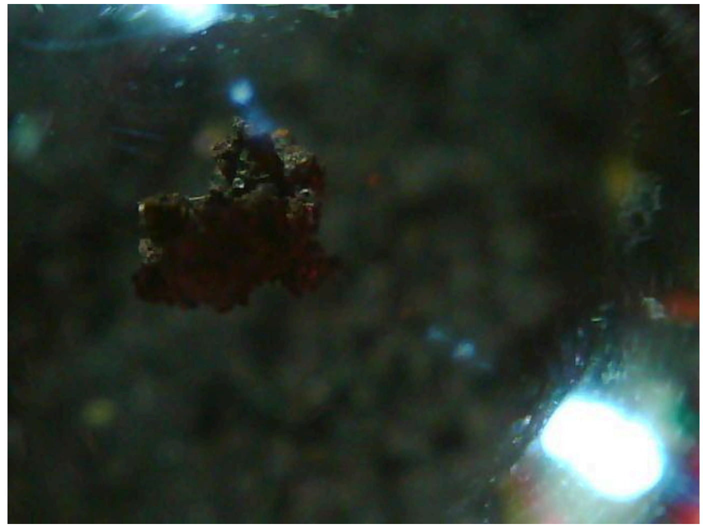
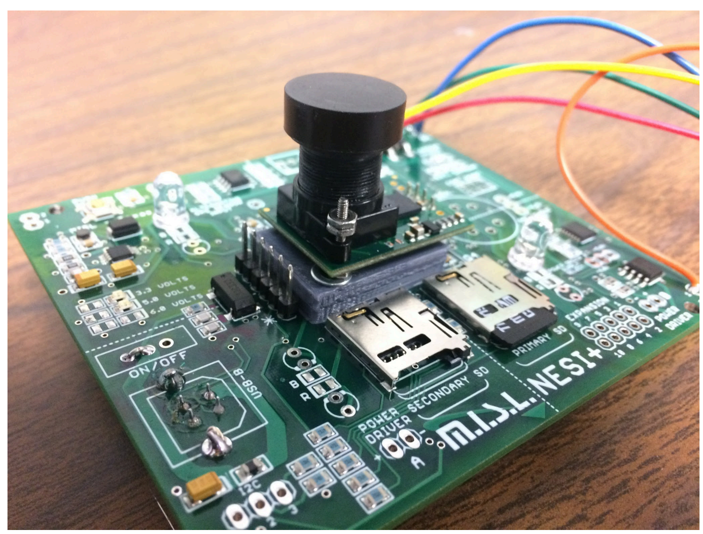
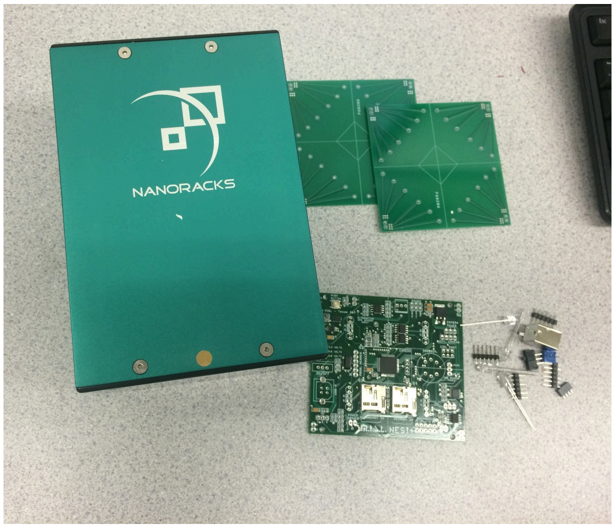
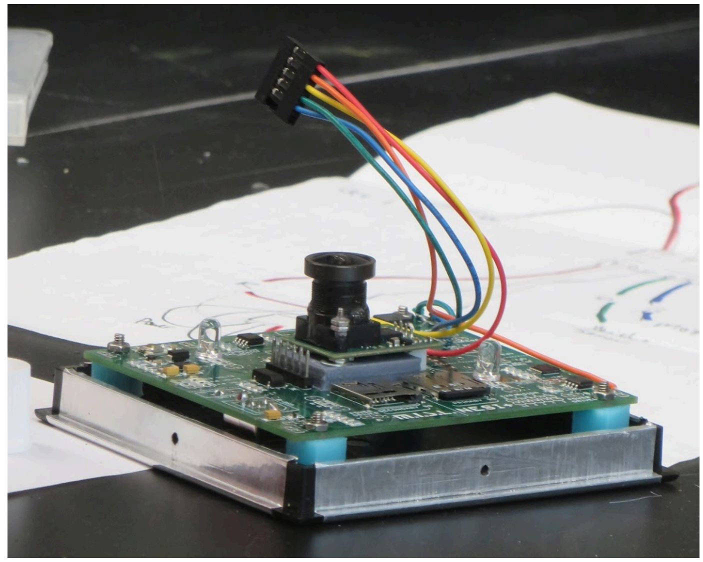

	

Image showing condensation, taken at time interval 1 sec after insertion	Images showing soil stuck on lexan during flight

NESI+ Board - Camera Spacer	
	
Student designed, 3D printed camera spacer	Camera spacer installed on NESI board

	
New Nanolab, NESI board, and sensors to replace the lost test module on CRS-7	Fully assembled NESI board with camera module and test chamber connector wire

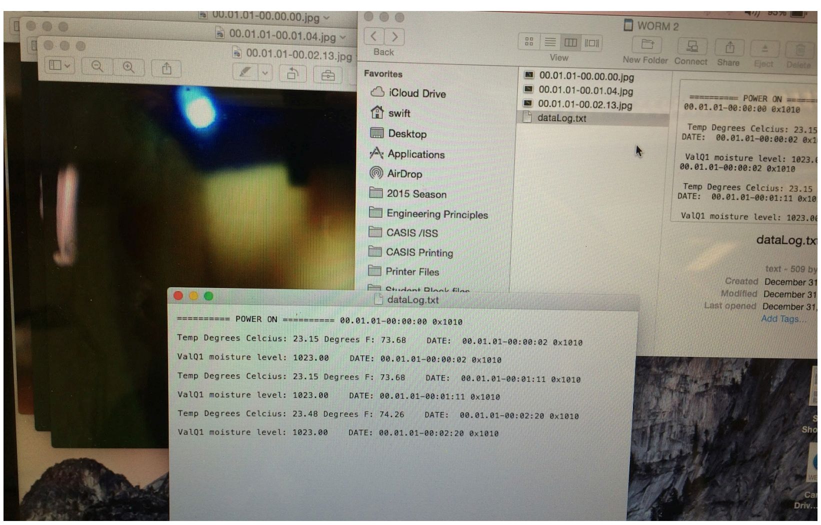
2.3 Software

In order to control the activity of the NESI+ board and all sensors attached, software had to be written. Software for the NESI+ board was written in a variant of C+, a program which none of the team members was familiar with. Over the summer leading into our first year of work a number of team members attended a three day course in order to familiarize themselves with use of hardware and software of the NESI+ board. In addition this preliminary training our group was assigned a graduate student at Texas A&M who was familiar with the board. He soon became instrumental to the success of our code, as we were often unable to resolve problems pertaining to the code.

There were a number of parameters which were taken into account while writing the code. We wanted our NESI+ to take temperature, moisture levels, and pictures at periodic intervals throughout the experiment. While first evaluating of necessities for the experiment, a nitrogen sensor seemed like it would be a valuable component of our data. Upon further research however, it proved unreasonable for both hardware and software reasons.

Testing, and focusing the camera became an evident problem early on. Code was written that took photos in 30 second intervals. This provided time to take and evaluate a photo, as well as adjust the camera focus before taking another picture. Through this guess and check method we were slowly able to focus the camera. Even after the camera was focused we continued to get corrupt files (as seen above). We learned later that a longer space was needed between photos taken in order to properly write photos to the SD card.

As shown below, the data was written to an 8GB SD card in a mostly raw form, with only a temperature conversion added to the code (Celsius to fahrenheit for simplicity's sake). Pictures were labeled with the date and time they were taken, as were the moisture and temperature readings.



Computer screen shot showing data collected from NESI board and sensors during one of the design test. Camera photograph, SD card datalog file and .txt file presenting temperature and soil moisture

3.0 Testing

3.1 Compost Testing

The testing goal for the biology compost team was to test the types of bedding that would be best for worm survival. This team did three major tests. The first test that this team conducted was looking at what is the best bedding to use that will hold moisture for a long period of time (one of the pieces of data that the software team programed was for levels of moisture through the test while on the ISS). The first was done with a mixture of peat moss, cardboard, leaves and coconut fiber. The teams used the following scale for moisture content during week long tests with these materials.

Level of Moisture	What does this mean
1023	No moisture content
700-1000	Low moisture content
500-699	Medium moisture content
300-499	Medium-high moisture
1-299	High moisture content

Based on the data of this test, it was determined that cardboard, leaves and coconut fiber held the best moisture content in module during these week long tests. These results were used in the final compost that was used in the module for the CRS 7 launch, along with shredded newspaper, oats, and deco beads (hold moisture). After the failed launch attempt of CRS 7, the module was changed to a closed module with a lexan closure on the top. With this change; the compost material was changed to just soil and worm food (food sent from Uncle Jim's Worm Farm) for the CRS 11 launch. This change was made so the one variable of composting (if the worms were able to compost or not) was tested while the module was on the ISS. The use of more materials used up more space so it was determined to use 5 worms in the module. The change to the new module and the decision to just use soil and worm food allowed the team to increase the number of worms in the final flight and ground based tests.

3.2 Cold Stow Testing

The students were split into two bigger teams; biology and engineering, then the biology team was then split into three sub-groups (experimental design, biology compost and biology testing). The biology teams started their work with looking at how the worms would adapt to the launch by lowering the core temperature of the worms which allowed them to go into a dormant state. The teams began their testing by placing the worms in a 4 degree celsius environment for different lengths of time (from 2 days to 7 days). These initial tests were done with just the worms in petri dish, these results supported the idea that the worms needed a form of insulation to successfully adapt to the cold temperatures. This led the teams to test the worms in the petri dish surround by gor-tex (oxygen exchange and insulation for the worms). These tests were done for the same duration as the previous tests. The data confirmed that the worms were able to survive in colder temperatures in the insulated petri dish or final habitat.

3.3 Capillary Action Testing

The biology team needed to find a way to keep the moisture levels up in the module for the duration of the test while on the ISS. With help and advice from a Colorado School of Mines graduate student, the solution researched was capillary action. This was a process known in plants to transfer the water into certain places of the organism. The goal was to help with the moisture levels in the form of small tubes in the compost/bedding material to transfer water from a reservoir of water into the compost/bedding material. The data for these tests showed that this could be easily done with the ground based module, but would require the addition of a small battery operated pump in the ISS module. This idea was quickly abandoned as the use of pump would have taken more room and would have added a battery component that would have used most of the room given to the worms in the module as well as the complexity.

3.4 Sponge Testing

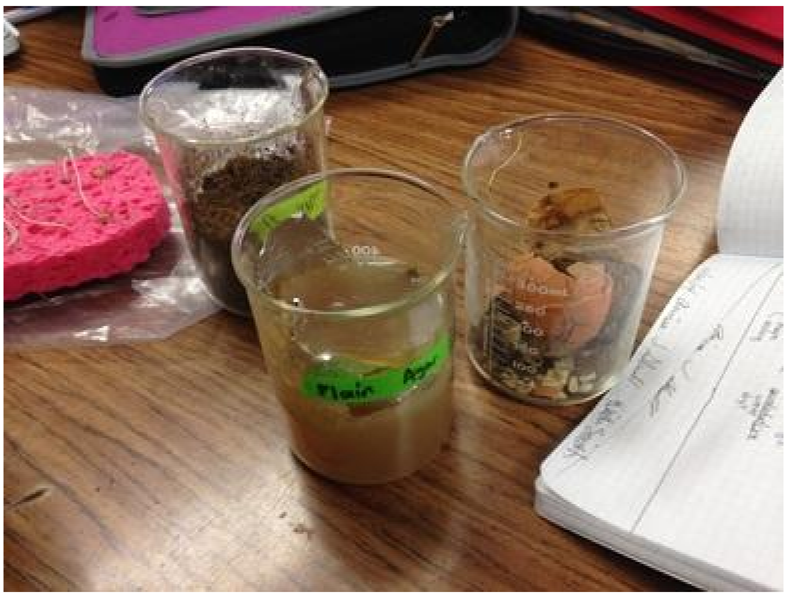
After the idea of using capillary action was abandoned, the team started to look at different options to help keep the moisture levels high during the flight and ground based tests. The next idea that the team came up was the use of moist sponges in the module that would be used to get water throughout the module during the tests. This test proved to be the best option for keeping the module moist during the tests. This also added insulation to the module for the worms during launch and while the module was plugged in on the ISS. The original design had three sponges adhered to both side walls of the module and the bottom of the module. During the long term tests before the launch of CRS 7, the team noticed that the moisture level stayed consistent. When the module changed after the failed launch attempt of CRS 7, the amount of sponges used went from three sponges to one sponge on the bottom of the module. This allowed for the addition of more worms, soil and food to be used in the test.

3.5 Vibration Testing

This biggest challenge in sending worms to the ISS, was the high vibration the worms would endure during launch. This team started with testing the effects of vibration on worm behavior and survival. Ethan Cranston from the structure team came up with a mechanism that would simulate the vibrations and G-force during launch. The students used this mechanism with dormant worms and undormant worms to test these effects on worm behavior and survival. The data showed that worms in an undormant state either did not survive the test or struggled to get back to normal behavior. The worms in a dormant state; took some time to start moving, but were able to survive the tests and were able to move normally through soil after they “woke up” from their dormant state. Students determined that the worms needed to be launched in cold stow early on in the design process.

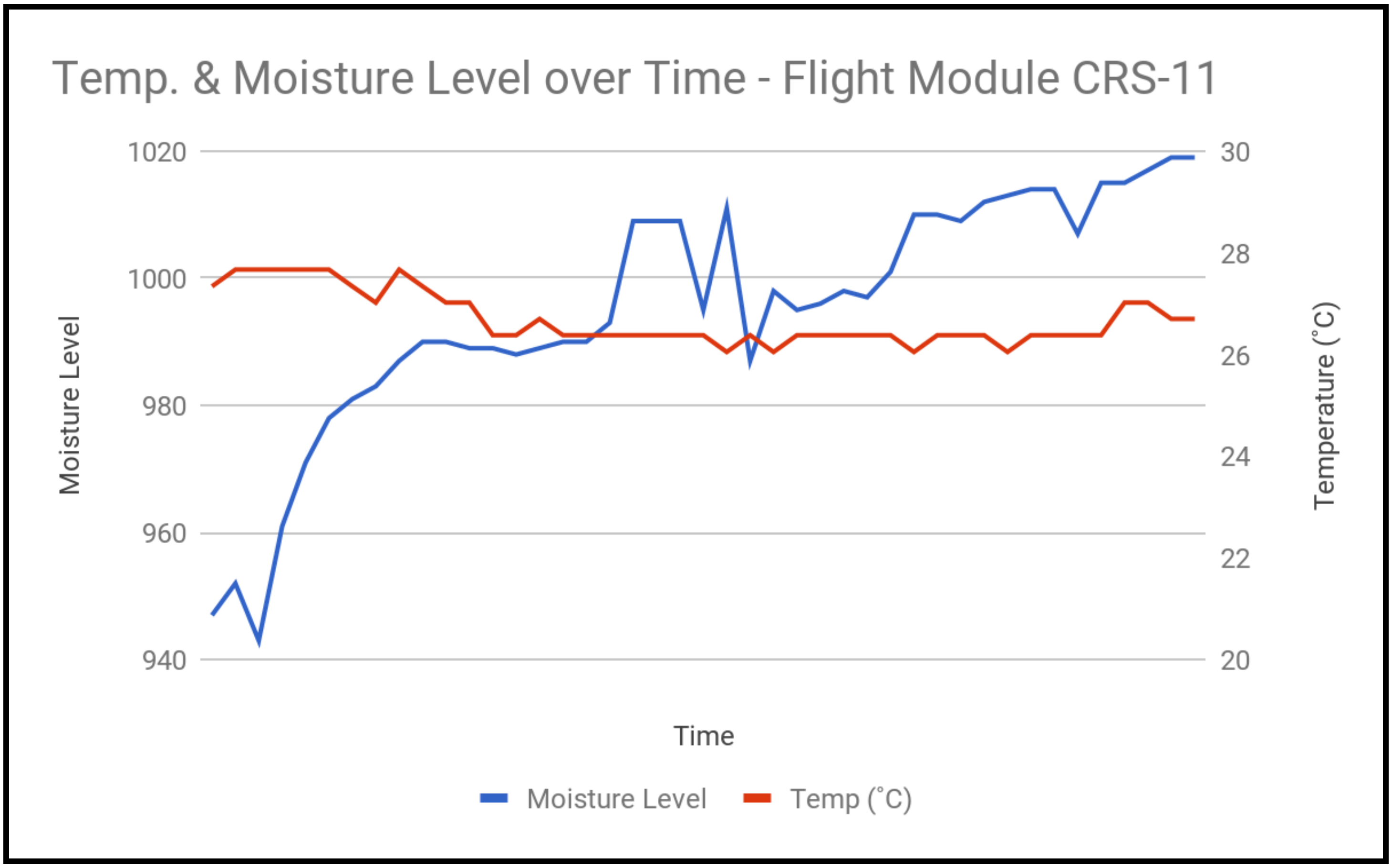
3.6 Agar Testing

Another major issue that needed to be tested was exploring different options for worm bedding to help protect them during launch and to keep moisture levels high. The team tested the use of Agar as a substitute for soil. As the team tested the worms in the agar solution, the data suggested that the solution held up in high vibration tests, but made it hard for the worms to travel through without adding holes to the solution. When the team added holes to the solution, the integrity of the agar was weakened and did not hold up in more vibration tests. The team noticed that the agar solution had a strong odor to it (this was a big concern on the ISS), so the team decided use the compost and bedding material that the compost team suggested.

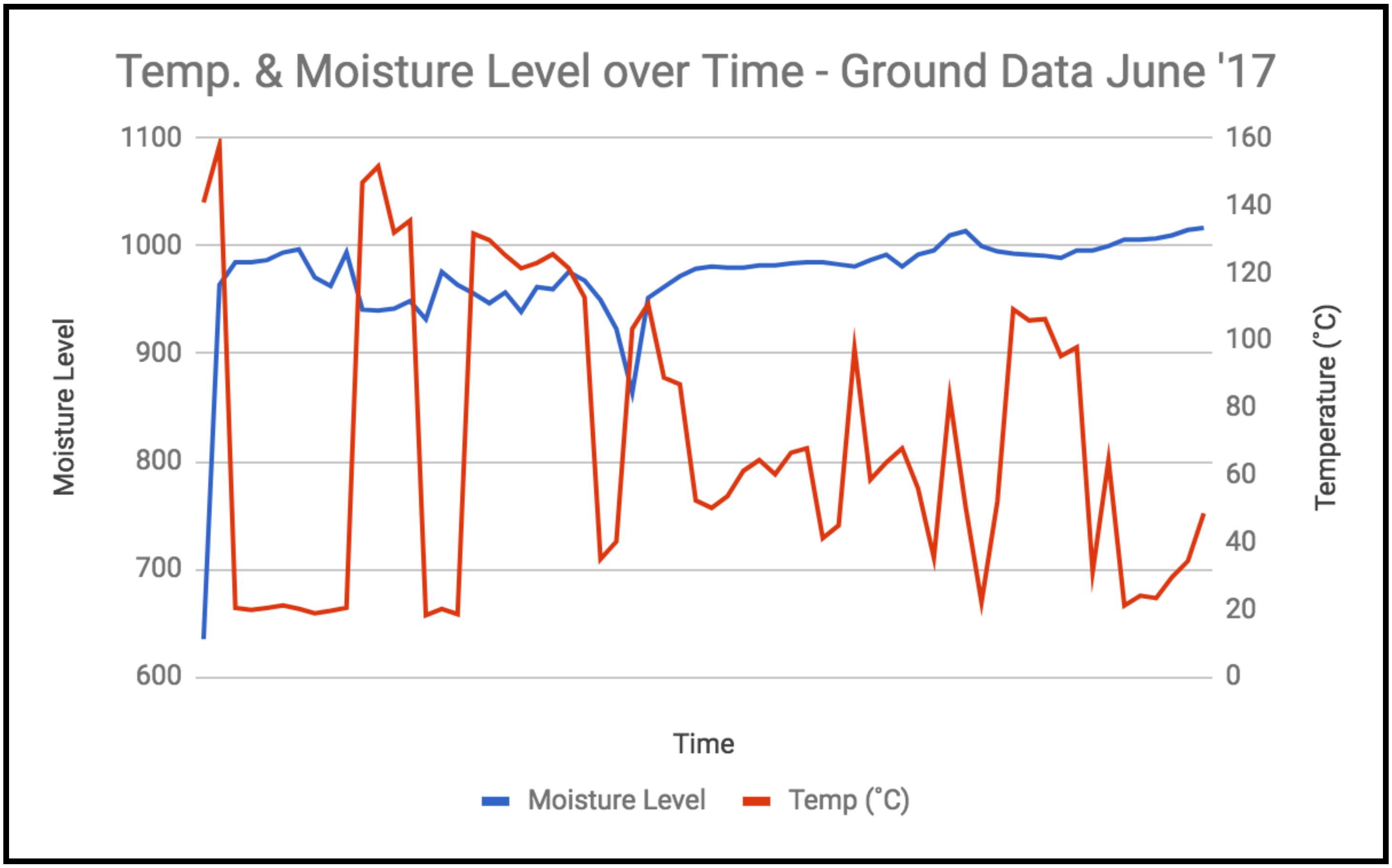
Agar Testing

Testing Agar for possible solution to vibration for the launch stage and re-entry.

4.0 Data

Below is the data collected from the temperature and moisture sensors on the NESI+ board during the International Space Station. 21 day test period in the microgravity environment.



Below is the temperature and moisture levels collected from the sensors in the NESI+ board for ground based data. 21 day test period in Golden, Colorado ending July 21, 2017.



5.0 Analysis

The students tested two different modules, there was a ground based module (module stayed on Earth) and a flight based module (module that was sent to the ISS). The two modules were prepped with the same amounts of soil (250g), worm food (10g), water (100mL), number of worms (12) and a saturated sponge (1) on the bottom of the module. Each module also included a camera for pictures during the experiment, a moisture sensor to test the moisture levels during the experiment and a temperature sensor to test the temperature of the module throughout experiment. Each module was placed in cold storage for a total of nine days and then plugged the module into the nanorack for the purpose of running the experiment for a total of twenty-one days. Once the experiment was ended, each module was placed in cold storage until data collection and analysis was done in mid-July 2017.

When the team received the flight module, they gathered at the local library to open up each module to gather the data from both experiments and to discuss what these results mean. The team decided to open the flight module first. Upon opening the module, there was a noticeable and unpleasant odor in the module. The team took the materials out of the module, looking for live or dead worms. The contents of the flight module, had some mold within the soil in the corners of the module. Remains of dead worms were found, but there was no evidence of living worms within the soil. Based on the observations of the remains of the worms, it was determined that the worms had died some time during the experiment on the ISS and began to decompose before being put back into cold storage for delivery back to Earth.

The camera sensor did capture a worm near the top of the module during one of the first few sets of pictures that were taken. The students believe that this is evidence that the worms were able to move throughout the module while in a microgravity environment. There were only a couple of good pictures the team could use in data collection on the flight module, as a couple of testing cycles into the experiment, a piece of soil stuck to the lexan and the camera focused on the piece of soil and not on what was happening below in the soil.

The temperature and moisture level readings were more helpful in analyzing what had happened while the module was on the ISS. The data for temperature while on ISS changed throughout the experiment. Once the module was plugged into the nanorack, the temperature slowly climbed to the ambient temperature of the ISS. Through the experiment, the students saw slight increases and decreases in the temperature readings, meaning that the worms were active during the time on the ISS. Based on background research, the temperature will increase when worms are actively composting. The moisture levels decreased over time during the experiment. This data was consistent with the tests that were done prior to the launch of the experiment.

Once the flight module contents were analyzed, the team moved on to analyzing the ground based module. As with the flight module, when the ground based module was opened there was a noticeable and unpleasant smell coming from the module. There was a thick layer of mold on the top of the soil, that was absent in the flight module. The team documented the initial observations, and proceeded to take the materials out of the module. The team looked for evidence of living or dead worms. The mold was found throughout the soil in the module, remains of dead worms were found in the module, but there was not any evidence of living worms in the module. Based on these observations, it was difficult to determine why the worms died in the module without looking at the camera, temperature and moisture data.

The pictures that were taken in the ground based module were clearer than the pictures in the flight based module. The pictures show a progression of the experiment as it ran. The first sets of pictures showed movement of the soil near the top of the module. About a week into the experiment the pictures started to show a progression of mold growing on the top of the soil. The pictures did not capture worms in the soil, but they did capture movement of the soil. It can be concluded that the soil movement was an indication that the worms were moving in the soil prior to the mold growing on the top of the module. These observations were surprising, so it was important to look at the temperature and moisture data to help in understanding what could have happened during the experiment.

Once the contents of the module were analyzed, the team looked at the temperature and the moisture data from the sensors in the module. The team looked for data that could explain the thick layer of mold on the top of the soil and explain why the worms did not survive during experiment. The temperature data shows inconsistent readings throughout the duration of the experiment. The temperature readings started really high and then dropped down to ambient temperature. The temperature readings ran at ambient temperatures for a several days and then increased dramatically. The temperatures remained at high temperatures for the rest of the experiment. The high temperatures of the module help to support why mold was able to grow on the top of the soil. The high temperatures in the module were too high for the worms to survive for the duration of the experiment. This explains why there was evidence of dead worms and no evidence of living worms in the module. The moisture levels decreased over time during the experiment, this data is consistent with the data from tests before the launch of the experiment.

Based on the vast differences between the flight and ground data, the team discussed possible reasons as to why the data was so different. A list of possible differences in each of the experiments was created and it was determined that there was a malfunction in the temperature sensor of the USB plug that the module was plugged during the experiment. The team felt that there were too many difference between the flight data and the ground data to make comparisons between the two tests, so it was decided that the team would get together to look at the possible problems with the module and sensors and run the ground based experiment again.

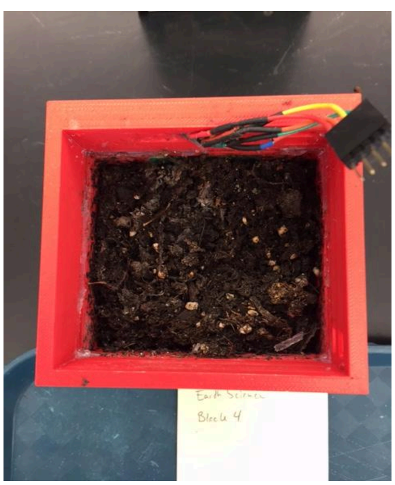
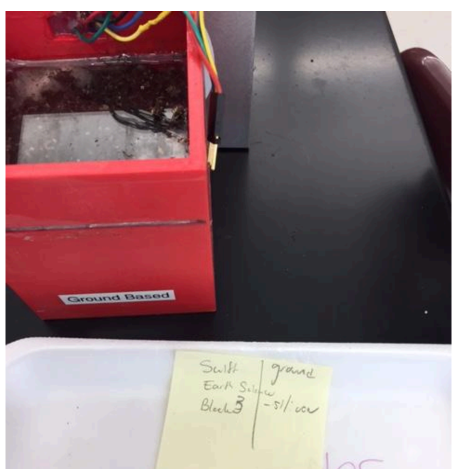
The team came back together about a month after analyzing the data for both the flight and ground based experiments to look at the ground based module to figure out what may have happened to the sensors or the USB plug during the experiment. The team decided to run the module without soil, food and worms to test the USB plug and temperature sensor. Through these tests, it was found that the USB plug was not working properly and the results that were recorded using this USB plug were not accurate. The module was then tested with a new USB plug, and the results from this test were more accurate. Once the USB plug was changed, the module was tested one more time without soil, food and worms to make sure that all of the sensors were working properly. The results of this final test showed that the sensors were working properly. The team then decided to re-test the module with soil, food and worms(same amounts used as before) for the same amount of time as the initial test in the summer.

The contents of the module were analyzed after it was tested for 30 days (cold stow with USB plug in time). The top of the module looked better (there was not a noticeable amount (if any) mold on the top of the module. The pictures from the module showed movement within the soil for about 14 days and then the movement stopped. The temperature readings showed the module stayed close to ambient temperature throughout the test and the moisture level dropped as it did before in the other tests. Looking through the soil for evidence of live worms was difficult. There was no evidence of live worms after this test, but the team was able to find evidence of dead worms. Based on all of the experiments that were run prior to the launch of the experiment to the ISS, the worms survived in the module during the duration of the tests. Based on these current findings (no evidence of live worms), the team began to look at variables that may have changed between the initial ground tests and the ground based test that was set up for the launch to the ISS. The one difference that was discussed was that the module was not sealed when doing trials before the launch, but was sealed for the final test in June. The team decided to run to side-by-side tests, one with sealant and the other without sealant to determine it that was the cause of the worms not surviving the test.

The next test had two modules set up in the same way with all of the same materials, the only difference was one module was sealed with the sealant and the other module was not sealed. These two modules were run for the same amount of time as before. When these two modules were analyzed, the sensor data was similar to the last test that was run. The pictures showed movement in the soil for about 14 days and then the movement stopped in both of the modules. The temperature and moisture levels were consistent with the last test as well. There wasn't any evidence of living worms in either module, but the team was able to find remains of several of the worms in each module. Based on this data, it can be concluded that the sealant did not have an affect on the module because in the last test the worms in both environments (sealant vs. no sealant) did not survive the test. The team was stumped on what may have happened in the test to cause the worms to die. The team gathered around the pictures and looked through them several times and noticed that there was movement to the top of the soil(it looked as it the worms were coming to the top of the soil and staying there), but the pictures didn't show the worms moving back into the soil. These pictures showed a similar pattern of what happened to the worms that were not tested (they came to the top of the soil and stayed there, eventually dying and decomposing on the top of the soil).

This observation was not what was expected to happen, so the team did some further research and found that red wiggler worms do not thrive in an all soil environment. Red wiggler worms tend to live near the surface of the soil or on top of the soil, and thrive in an environment that has a higher compost to soil ratio. In the final test, the team had decided to make most of the environment soil with a smaller amount of worm food (compost) mixed into the soil. It can be concluded that the worms did not have enough compost material to survive the test, and the environment that they were in was too high in soil. In order for the worms to thrive this environment and show signs of composting, it was discovered through this experiment that these worms needed an environment of a small amount of soil and higher amount of compost material.

ISS and Ground Based Module Analysis July 2017 Golden, CO.		
		
Flight based module analysis	Top view of ground based module	Mold layer found at the top of the soil in the ground based module

Side - by - Side Sealant vs. Non-Sealant Analysis: December 2017, Golden, CO		
		
Ground based module without sealant	Ground based module with sealant (mold in upper left corner)	Close-up of ground based module with sealant

5.1 Future Revisions

Hardware and Software Revisions

Primarily, the refinement of the code would better the experiment through the averaging of data points real time. Secondly, simplifying the layout and amount of character on the raw output data would doubtlessly result in a much smoother collection and analysis of data.

Biology Revisions

Based on the findings of these experiments, some revisions to the habitat for the worms would yield better results. Red wiggler worms thrive in an environment mostly composed of compostable material. They do live near the surface of the soil, so the habitat should only contain a small amount of soil. The bulk of the habitat should contain organic compostable material for the worms to live in. This revision would create an environment in which the worms would thrive in and would survive the duration of the test.

The compostable material also would need to be tested for mold growth and odor. When mold is produced it can lead to a strong odor and can cause individuals to get sick when they come in contact with it. The compostable material would require further testing to determine if mold would grow in the presence moisture and if there is a correlation between mold growth and the release of strong odors. The ISS is a small, closed environment, so if there is a correlation between mold growth and odor, then using a compostable material that has no mold growth is the desired material to use in the habitat.

6.0 Impacts

6.1 Learning and Experience Based Impacts

Overall the impact on those directly conducting the experiment was a lesson in the importance of meticulous work that is proved by data as well as knowing the influence of losing work and the determination needed to succeed. Specific areas that showed this include record keeping, communication, research and testing procedures. It also impacted the motivation of certain students due to the launch of the CRS-7 and knowing that a year's worth of work was among the products and technology aboard when the anomaly occurred resulting in failure. This brought a small group of students together to continue the project and persevere through the next 3 years and therefore the next launch of the CRS-11.

Record Keeping

During the project records were not kept in an orderly fashion nor were they updated regularly. To improve this a Google Folder could be shared with the entire class. Teams would then be given individual sub-folders where all information, ideas, or research done by the teams would be recorded and open to everyone in the class. Resources would also be cited in folders which would supply a database to look back to later in the project. By recording information this way communication errors would be kept to a minimum, every individual would have access to every teams data and ideas, which would mean individuals could be easily caught up if they missed anything and work could be looked back onto by anyone at any point. By recording information communication, research and testing repeats and errors could be avoided entirely, this would mean more time was spent working on the project rather than working out what had already been done or discussed.

Communication

Better communication within and among groups would allow everything to run more smoothly and with higher efficiency. During the project students each had their own goals for the project and ideas on how to accomplish them. This sometime interfered with how student communicated. To improve this students should remember to be open to others ideas and set goals collectively. By adding a team meeting each week, rather than only having them sporadically these goals could be met. Team meetings would be used to discuss the progress of each team, reassess and set goals to accomplish together. By doing this the door for the worms would have been removed sooner, the design of the test chamber would have been simplified sooner, experiments would have been less likely to be repeated and each team would be up to speed which would allow for more efficient work. Meetings would be recorded via notes and goals and saved in a subfolder of the Google Folder. This would also allow for reflection on how the class has progressed and if there are any patterns of thought.

Research

Students only did a small amount of research prior to starting experiments and design and what research was done was not recorded or cited. Some research that could have been done before work began includes what Red Wiggler worms eat, how much water they need daily, how much space each organism needs, how much oxygen they need and therefore how many to put in the test chamber, and research on the habitat of Red Wiggler worms by every team. Research would then be recorded and cited in the Google Folder. By doing this all research could be looked back upon and new research could be added. Sources would then be reliable and referenceable which would allow for students to make and backup informed decisions on how to proceed with various parts of the project.

Testing

The testing done was rarely under controlled circumstances. Because of this changes in the test chamber and compost/bedding were sporadic and uninformed. To improve on this all tests should be run in the same conditions for the same length of time as other tests of that category (i.e. short term, mid term and long term tests). For every test run a full report should be written with a purpose, hypothesis, procedure, data, analysis and conclusion. These reports would then be saved in the Google Folder. An overview of all the tests would also be included. This would mean tests would be less likely to be repeated and circumstance would be more controlled. Finally several full tests with every variable the same as the true test should have been run prior to launch. This would provide an opportunity to fix any issues with the test chamber and provide a baseline of data for the actual test. This would also mean the failure of the ground test would be less consequential.

6.2 Scientific Impacts

Discoveries and New Theories

Because of the inconclusive results from the experiment sent to the ISS there is not enough evidence to back up the theory that Red Wiggler worms can vermicompost in microgravity. However there is evidence to prove that the worms can survive the journey to the ISS. This is important because no evidence contributes the microgravity environment to the death of the Red Wigglers but rather outside factors that were later theorized to be a lack of compost diversity and oxygen deprivation. Because of this it is believed that there is a strong possibility of successful vermicomposting by Red Wiggler worms in microgravity.

Where Next

With improvements made to the test chamber that would increase the flow of oxygen, a more suitable mixture of compost and several successful ground tests Red Wiggler worms could be sent back to microgravity to prove their ability to compost in that environment. From there vermicomposting could become an integral part of the ISS waste disposal system and potential farming program by providing a renewable way to dispose of waste and a constant source of non-toxic fertilizer to replenish soil in ISS gardens.

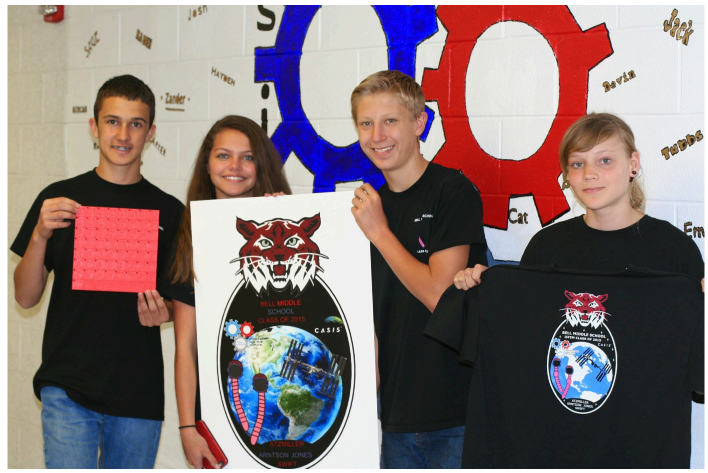
Long Term Goals

With the ability to run a vermicomposting system in space it would increase the distances and time that humans could travel and spend in space by giving them a renewable source of nutrients for crop soil. This could be applied to colonies on Mars and long term space travel to outer planets.

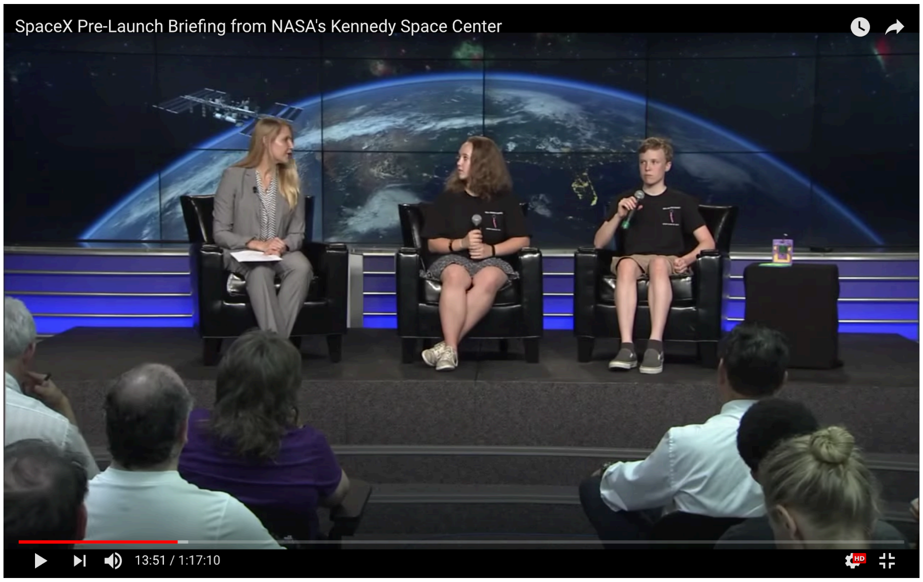
6.3 Community Impact

Through this project the community was able to watch aspiring scientists and engineers experiment and learn. The CASIS project was shared with the community through several news sources. The project also brought students several opportunities to meet with respected members of the community to receive recognition for their work. These opportunities are highlighted in the examples below.

CASIS National Design Challenge - Student artwork

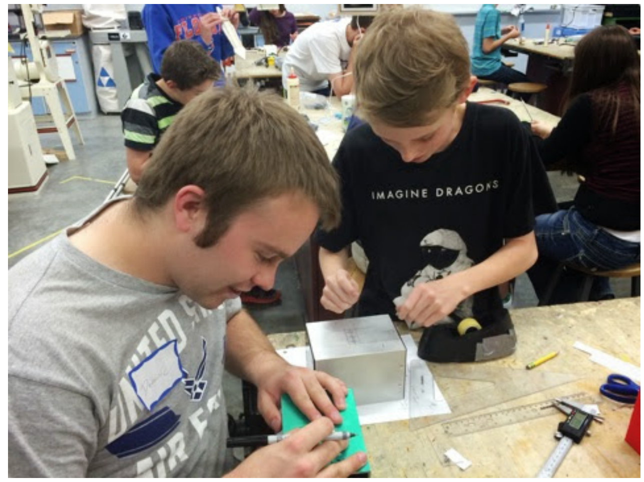


Student designed sticker, flight patch and t-shirt representing the Bell Middle School bobcat mascot, worms, ISS, CASIS, iSTEM program and teachers involved in the project. The patches and stickers gave people within the community a tangible way to connect to the project.

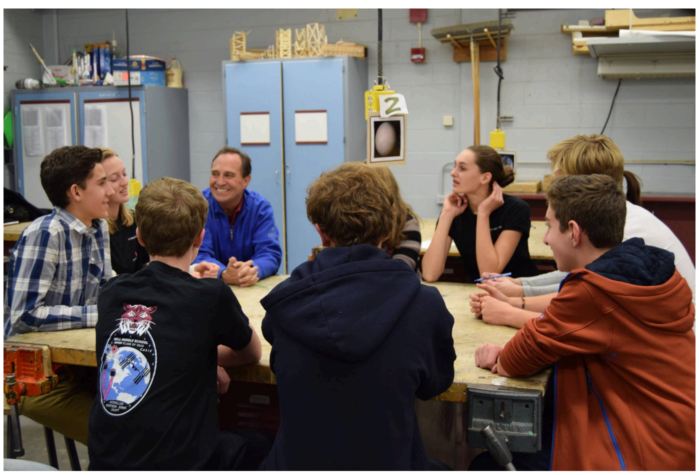
CASIS National Design Challenge Community Impact
 **NASA CRS-7 Pre-Launch Briefing -** Bell Middle School 8th grade students, Heidi Smith and John Weiler, shared with reporters and the host about the CASIS National Design Challenge and the experiment on June 27, 2015 at Kennedy Space Center prior to the CRS-7 launch. This opportunity was a great source of pride within the community. It showed the perseverance and intelligence of students and teachers and gave them recognition within the community. Link: https://www.youtube.com/watch?v=l6GmuRY5bHA
 Education Payloads Launching to the International Space Station - Ken Shields from CASIS, Shanna Atzmiller, Jesse Swift and students show the work they did throughout the school year before the launch of Spacex CRS 7. Similar to the CRS-7 Pre-launch Briefing video this is an example of the recognition that the participants received from CASIS and an opportunity to meet those whom gave grant. Link: https://www.youtube.com/watch?v=yX3MyVgU7Ew&t=1s

CASIS National Design Challenge - Community Impact

Bell Middle School students receiving the Sustainability Award from the City of Golden for their work on composting for the CASIS Design Challenge. This award was a tangible example of how the students and teachers were recognized for their persistent work.

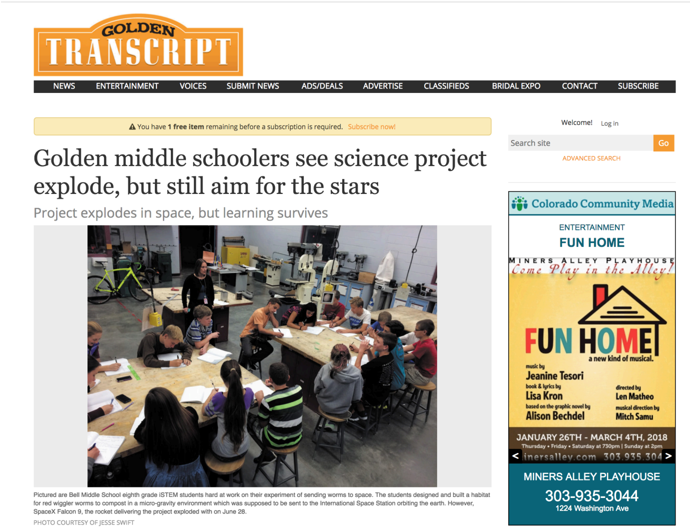
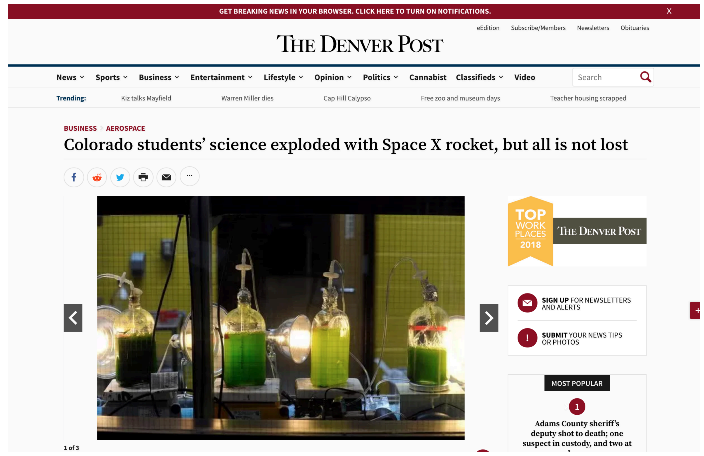
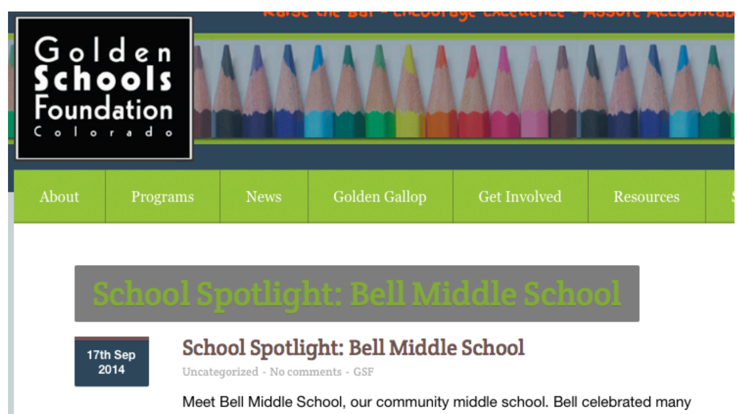


Colorado School of Mines mentor student works with 8th grade CASIS student in design and preparation of the Nanolab modules. This opportunity allowed for students to learn and grow from some of the brightest in the state and an opportunity to network with graduate students.



Congressman Ed Perlmutter visits with the CASIS Vermicomposting students. This was another opportunity for students to meet a respected member of the community and showed how students and teachers were recognized for their work.

Bell Middle School students participated in the City of Golden Holiday parade sharing with the community the ambitious project the students are participating in.

CASIS National Design Challenge - Community Impact	
	
Article from local paper The Golden Transcript about the loss of CRS-7. This is an example of how the project was recognized in the community and highlights the learning impact of the project for both students and teachers. Link: http://goldentranscript.net/stories/Golden-middle-schoolers-see-science-project-explode-but-still-aim-for-the-stars,193926	Article in The Denver Post about the lost of CRS-7 and the CASIS National Design Challenge student's work aboard the payload. This is another example of recognition received from the surrounding communities. Link: https://www.denverpost.com/2015/06/29/colorado-students-science-exploded-with-space-x-rocket-but-all-is-not-lost/
Heidi Smith, front left, and fellow students, clockwise, Anissa Shull and Alexa VanSchaardenburg chat with Rep. Ed Perlmutter about their project on Dec. 14 during the congressman's visit to Bell Middle School.	
Article from local paper about the opportunity for a relaunch of the project. This article highlights the communities continued interest in the project even after the failure of the first. http://goldentranscript.net/stories/golden-students-worm-project-gets-second-chance-to-head-to-space,204126	Golden Schools Foundation of Colorado recognize the iSTEM program at Bell Middle School. This shows how the project garnered interest, even early on, from the community. http://goldenschoolsfoundation.org/school-spotlight-bell-middle-school/

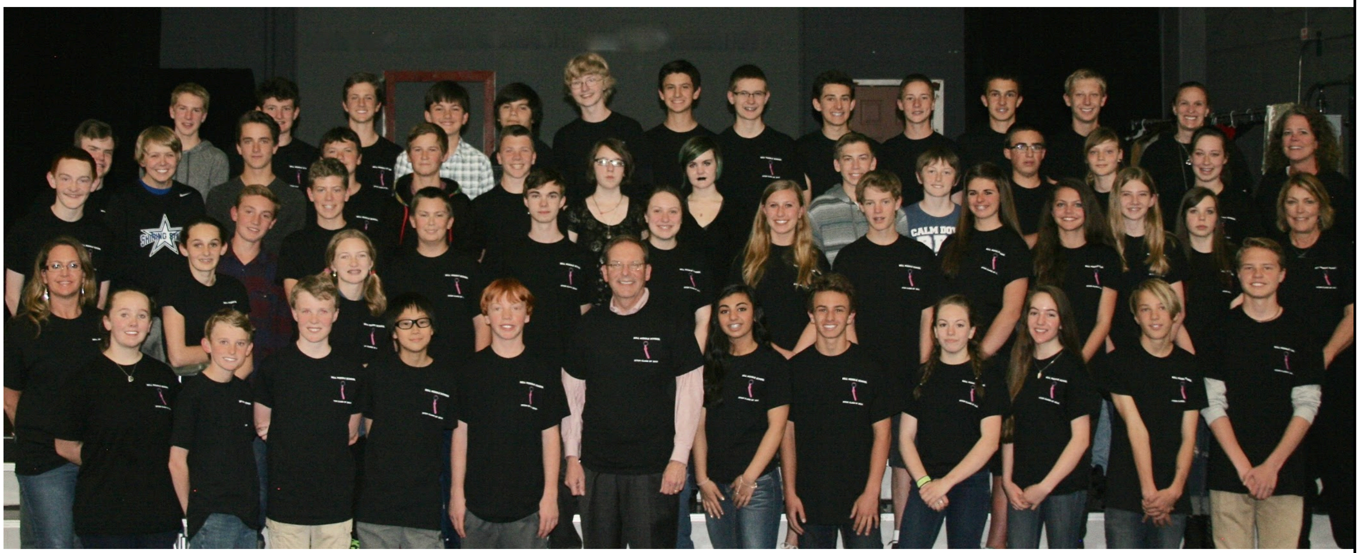
7.0 Participating Members

The CASIS National Design Challenge was awarded to Bell Middle School in Golden, Colorado in May of 2014.

The principle of the school was Bridget Jones. Andrea Schulz and Susan Arntson were assistant principals. Jesse Swift and Shanna Atzmiller were teachers and mentors to students.

Photo: May 22, 2017 - Student scientists at last meeting prior to CRS-11 launch

Gold Level Student Participation
Anissa Shull, Alexa VanShardeberg, Linus Woodard, John Weiler, Zak Chorny
Silver Level Student Participation
Alex Townsend, Jonah Wimbish, Heidi Smith, Artie Battaglin, Ashley Gerwing, Foxton Robie, Ethan Cranston, Angelee Rose

iSTEM Class of 2019

(Left to right, top to bottom) Josh Thomke, Dylan Scherer, Joe Brock, Jake Fettig, Grant Schomosa, James ..., Ben Brock, Ethan Cranston, Alex Townsend, Patrick Dolan, Patrick Bentfield, Jonah Wimbish, Shanna Atzmiller, Ryan Blackmon, Miles Dempsey, Porter Windel, Aydan Roth, Adam Blackstock, Brady desGarennes, Hailey Cross, Heather Giddins, Trevor Reed, Jack Rosener, Jason Weimer, Amber Chaney, Miranda Hayes, Bridget Jones, Chance Grotwal, Tristan Huskie, Dylan Smith, Zach Higgins, Malachi Sparks, Emma Bruce-Brown, Ella Poskie, Brennan Oakleaf, Angelee Rose, Taylor Worsham, Ashley Gerwing, Olivia Bohl, Susan Arntson, Andrea Schulz, Alexa VanSchaardneburg, Anissa Shull, Heidi Smith, Artie Battaglin, John Weiler, Noah Zhao, Hans Peterson, Ed Harris, Geetali Lal, Linus Woodard, Mady Larson, Cheyenne Cavender, Alex Bas...., Foxton Robie

8.0 References

Teacher References:

Shanna Atzmiller shannaatzmiller@gmail.com
303.902.8999
13260 W. Coalmine Dr.
#217
Littleton, CO
80127

Jesse Swift jesseaswift@gmail.com
720.352.7813
1526 Meadowlark Lane
Golden, CO
80403

Student References:

Anissa Shull anissashull@gmail.com
303.906.9152
625 Canyon Point Circle
Golden, CO
80403

Alexa VanSchaardenburg alexa.vsdb@gmail.com
720.412.7004
360 White Ash Dr.
Golden, CO
80403

John Weiler johnweilerr@gmail.com
303.974.0283
2055 Crestvue Cir.
Golden, CO
80401

Linus Woodard linusqwoodard@gmail.com
303.505.1826
101 Eagle Ct.
Golden, CO
80403