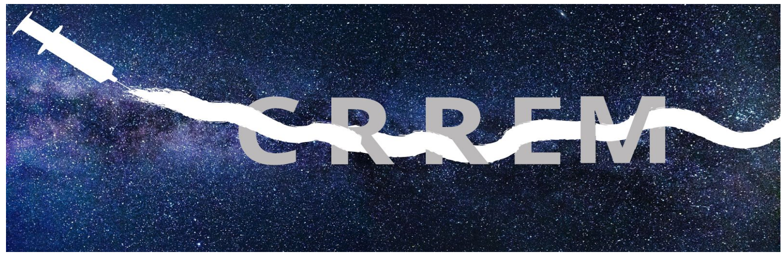
Project Title: Comparison of Reaction Rate on Earth and in Microgravity (CRREM)
Team Name: Spaceutica
Team Members: Ryan Chang, Kevin Chen, Domenic Fong, Jae Hee Hong, Rohan Jagtap, Emily Tan, Chloe Taylor, Jenny Tindall, George Wan, Joanna Xu



Link to team video: https://youtu.be/jNpEP6N6JEQ

The purpose of our experiment is to observe if there are differences in the dissolution rates of a bone mimic in microgravity compared to that on Earth. To study “how we might understand how wounds heal in reduced gravity”, we started by researching the effects of bone loss and its impact on individuals. We discovered that bone loss in space is a major health concern for astronauts, but is not completely understood.

Simplified, bone health depends on the balance between two cell types: osteoblasts and osteoclasts. Osteoblasts build new bone and repair old bone, while osteoclasts secrete acids which dissolve existing bone. In reduced gravity, osteoblast function reduces while osteoclast function is believed to increase slightly. This imbalance results in bone loss because the osteoblasts can no longer keep up with the osteoclasts. Research on bone loss in space revolves largely around osteoblast function, but we wanted to study the involvement of osteoclasts instead. We hope to test our hypothesis which predicts that bone dissolves more quickly under microgravity conditions (as compared to 1g).

To mimic the function of osteoclasts, we designed an experiment with two key components: hydroxyapatite as our bone mimic and acetic acid as our osteoclasts. Using an arduino and an accelerometer that senses microgravity, our experiment can be performed precisely within only 3 minutes. Once in microgravity, the motor connected to the arduino triggers an action that results in the manipulation of a syringe containing the acid. This motorized syringe releases acid into a smaller box containing the bone mimic. During the three minutes, the acid would dissolve the bone as a magnetic stirrer, activated by a fan (attached to the arduino), mixes the solution. This stirs the solution so that when the motorized syringes intake the 30ml sample again after 3 minutes, the sample will be a homogenous mixture of acetic acid and calcium ions. This sample will be titrated on Earth to find the amount of calcium ions that dissolved from the bone, which we would then use to find the reaction rate.

The results of our experiment would direct future research concerning spaceflight induced osteopenia and confirm whether or not osteoclasts are a significant contributor to bone loss. Our budget fits within the given grant at $1007.30 and accounts for all the materials used in our experiment.

Project Overview

In an ever expanding universe, planet Earth is seemingly insignificant; a mere speck of dust drifting through the prodigious cosmos. Paradoxically, Earth, a place relatively unremarkable, has given rise to complexity along with the very agents capable of contemplating and admiring the fact of existence. Almost as if the unexpected is to be expected. Humanity need not be limited by its place of origins, but must look beyond the horizons if it is to accelerate progress. It must leave the comfort of its home and embrace the prospects that come with infinity. Space travel is beginning to transform this realization into a reality and has shown tremendous potential for expanding scientific knowledge. Unfortunately however, space travel is only in its infancy, and those courageous enough to reach for the stars are burdened with debilitating obstacles. One of the most serious being the rapid deterioration of bone mineral density which depletes by approximately 1.5% each month. This fact is one of the greatest barriers to long term space travel and has effectively restricted space related research. Our design team has acknowledged that resolving this issue must be made a major priority and have devised an experiment which we believe would lay the framework to finding a viable solution. As Carl Sagan once said "somewhere… something incredible is waiting to be known," but, in order to get to that "something" the journey must first be made possible.

Background Knowledge - To preface the following section, a basic understanding of the bone remodelling process is essential. Bone is a dynamic structure which is maintained by the synergistic action of two cell types: osteoblasts and osteoclasts. Osteoblasts are responsible for producing new bone and repairing old bone whereas osteoclasts make and secrete digestive enzymes that dissolve bone tissue. The interplay between these two cells is fundamental to the maintenance of good bone health. An imbalance between the ratio of bone breakdown to repair causes major problems such as bone loss in space. Much of the current research regarding this issue has focused on osteoblasts whose function diminishes in microgravity. Osteoclasts are less extensively researched, although they are believed to operate at an increased rate. Understanding the extent to which the rate of bone breakdown differs under microgravity would be monumental to directing future research and developing pharmaceuticals.

Impact - With this in mind, our experiment sets out to determine the difference in the dissolution rate on Earth under gravitational forces as compared to microgravity. We will accomplish this by mimicking the bone breakdown process as mediated by osteoclasts. The observed reaction rates would shed light on the true cause of bone loss in space. Specifically, whether osteoclasts play a significant role in the deterioration of bone tissue in space or if another factor is responsible. No matter our findings, useful information will be obtained. Firstly, if the reaction rate is significantly higher in microgravity this would indicate that osteoclasts play a greater role in space flight induced osteopenia than originally believed. This result would lead scientists to develop a solution more rapidly. Secondly, if the reaction rate is around the same, this would confirm the notion that bone loss is mainly due to the decreased function of osteoblasts and is not correlated with changes related to osteoclasts. This would support previously published research. Finally, If the reaction rate is decreased, further inquiry would be prompted as this result is unexpected. Additionally, if any change in the dissolution rate is observed the experiment would offer insight into chemical kinetics. Specifically, how the laws governing this science are influenced by microgravity, which could have a variety of ramifications judging by the fact that much of modern medicine relies on dissolution reactions.

Further Implications - The findings of our experiment are not intended to resolve spaceflight induced osteopenia directly, but act as a guiding hand, pushing scientists on the path of research with the most potential. Initially, the results would be of most importance to research scientists, who, building upon our conclusions, could develop drugs and various strategies for treating microgravity induced health concerns. This would then work to benefit all those wishing to partake in space travel. Further studies stemming from our project would help to negate the health related risks of space travel, minimize the time which astronauts must dedicate to preserving and rebuilding bone mass as well as potentially lead to breakthroughs which aid in combating debilitating diseases such as osteoporosis. Our information will be shared with the scientific community through the composition of a research paper, speeches and verbal interactions, social media efforts, and the publishing of the quantitative data that we record. While the information obtained from our research alone would be small, it would lay the framework for something much bigger. It would contribute to building a future where long term space travel and human civilizations on other planets are realities. Supporting our visions and ideas would be an investment into a future filled with potential, where the sky is no longer the limit!

Hypothesis - During the bone breakdown process, osteoclasts secrete acid in order to break down hydroxyapatite (HAP), the inorganic component of bone. Given that bone loss progresses rapidly in space, it is reasonable to conclude that a changed dissolution rate may be a factor in the latter problem. As such, our team has predicted that the dissolution rate of HAP brought on by CH_3COOH will be greater in microgravity as compared to 1g conditions. We will test our hypothesis by dissolving a sample of HAP (in CH_3COOH) over the three minute period of microgravity. After said time has elapsed, a sample of the resulting solution will be extracted, and analyzed using EDTA titration methods. Employing $[Ca^{2+}]$ as an indicator, the amount of dissolved HAP can be determined, which then can be manipulated into a rate. A similar procedure will be followed on Earth, and the dissolution rates will then be compared.

Relevance to Space - Unlike previous investigations, our experiment has a clear focus and through troubleshooting, we have effectively isolated one variable: gravity. We have done our best to eliminate all confounding factors and have implemented various strategies to combat the sources of error we identified. Finally, our methods will generate data describing the rate at which bones are broken down in microgravity (this has not yet been accomplished). Access to a microgravity environment is vital to the success of our assessment. In order for the difference in rate to be determined, samples of the dissolved solution must be taken both from Earth and a location where gravity is not a factor. From a mere three minutes in microgravity, our team will be able to add previously unknown numerical figures concerning the breakdown of bones in space.

Experimental design - Contained within the payload are two smaller boxes each equipped with their own bone mimic (HAP), mixing mechanism (to ensure the uniform spread of Ca^{2+} ions), and a syringe containing 30ml of dilute CH_3COOH. In short, our experiment functions in the following way: once the experiment enters microgravity, an accelerometer signals the syringes which are motorized to inject the CH_3COOH into the individual boxes. During the three minutes, the HAP will dissolve while the mixing mechanisms ensure all particles are dispersed evenly. At the end of the three minutes the same syringes will extract a sample of the solution to analyze back on Earth. Causes for concern such as G forces, temperature and external vibrations have been carefully considered and suitably countered. G forces would not impact the experiment given that it begins and ends all within the period of microgravity. The vibrations of the spacecraft would not be harmful and could potentially help homogenize the calcium ions into the solution alongside our mixing mechanism. Temperature will be recorded to ensure that microgravity is the only variable which changes.

Experimental Procedure - In order for all this to take place successfully, several steps must occur. In advance of the launch, the experiment must be constructed and tested thoroughly. We must ensure that all components of the experiment are functional and make adjustments accordingly. All elements which rely on technology will have to be programmed in advance so that the experiment may occur remotely. This includes the syringes which will be motorized, the mixing mechanisms which consist of a fan and two magnets (the rotational force generated by the spinning motion of the fan, coupled with the magnetic field of the magnets will allow for a stir bar to agitate and homogenize the mixture) and the accelerometer which will all operate and receive commands from an arduino. Immediately prior to the launch, the syringes must be filled and the bone mimics will be fastened in place. Upon landing, the samples will be collected and analyzed in a lab.

Payload Requirements and Risks - As our experiment includes both chemicals and motors, we took precautions to ensure that it satisfies the Payload Requirements. We measured every component in our experiment and calculated a design that fit into a 4x4x8 inch box and is under 1.1lb. Our bone is held intact so the design is flexible to reorientations. The technical items do not run on batteries nor do they exceed the 5V of 0.9A power supplied. Lastly, we are only using 60ml of liquid and will ensure that our container (box) is leak-proof. We will take safety precautions to ensure that all chemicals and electrical hazards are handled appropriately so as to minimize the risk to ourselves. Potential sources of error include the timing of the motors, the failure of the mixing mechanism, a reaction rate which is too fast or slow to be distinguished from error and an inability to inject the acidic component due to the formation of a vacuum. To mitigate these risks, our team has done the following. We will program the motor so that the signal is received at the right time and we will test it extensively to ensure functionality. We will place a mesh around the stirrer to keep it within the magnetic field of the fan thereby guaranteeing that the stirrer continues to spin and creates a uniform solution. Through trial and error we will learn which concentration of acid produces results within the time constraint and make change accordingly. Lastly we have combated the issue of the vacuum by integrating a gore tex membrane into our design which will allow air to escape while containing the liquid.

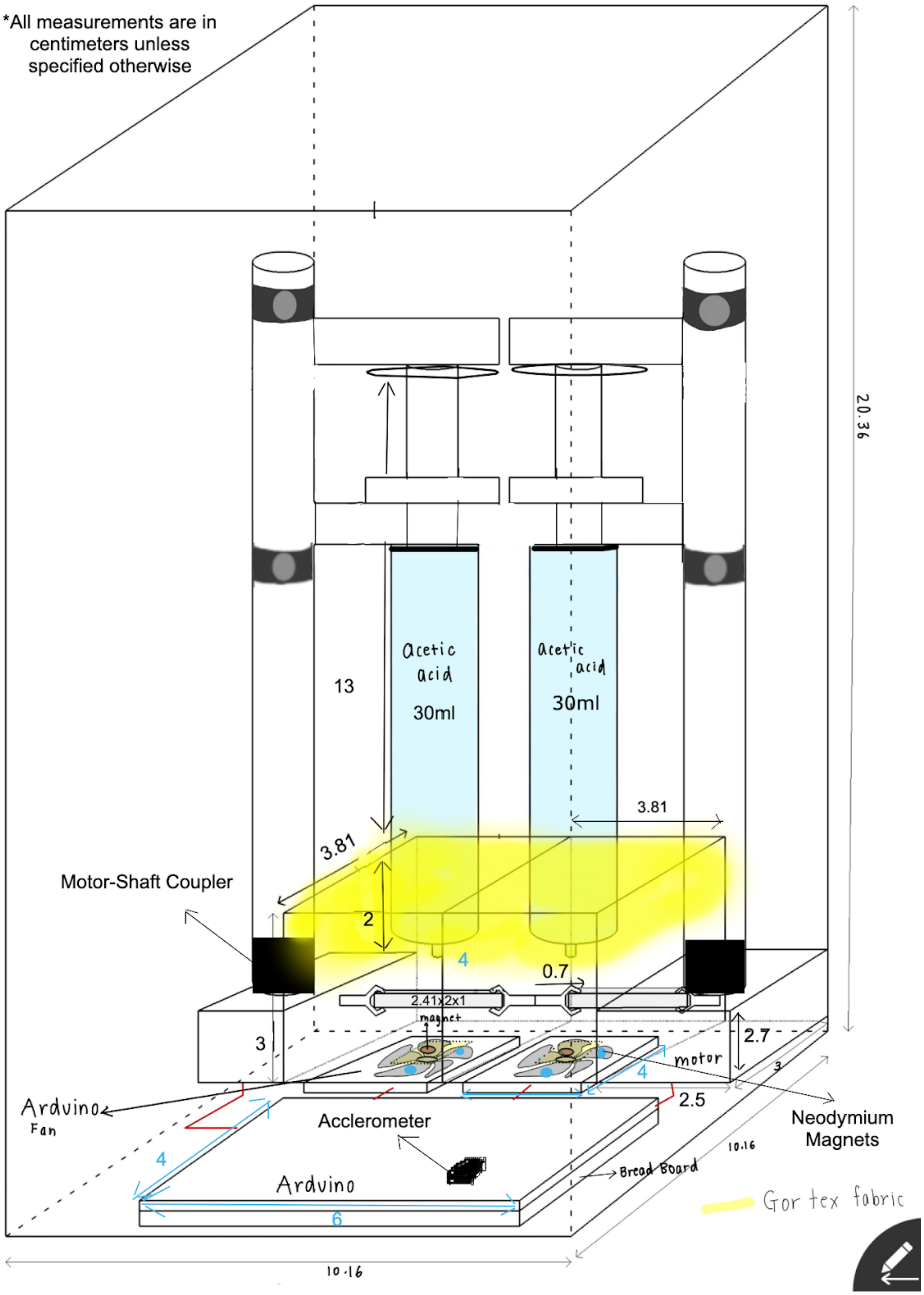
Team Structure - The success of a team is largely contingent on its ability to work together. Seeing as obtaining a favorable outcome is a priority amongst us all, we will do whatever is necessary to ensure effective collaboration. Each and every member of the group has a very specific and distinct set of skills and the diversity in our abilities will allow for the necessary roles and responsibilities to be fulfilled. We will need individuals who are capable of programming, building, designing, troubleshooting failed experiments, performing titrations, overseeing chemical reactions, marketing/promoting our findings, purchasing required materials and performing relevant calculations. Our team has the benefit of living in very close proximity to one another. We are all located in and around the greater Vancouver area and would likely have no need to build the project remotely. We plan to partner with a lab or university and build the payload at the discretion of our associates. However, if we had a need to do this remotely we would be able to do so by designating specific members, specific tasks and communicating frequently using social media.

Team Management - The journey leading up to the flight is a long and tedious one but through precise and strategic planning, our team will be able to execute this mission. We have scheduled a deadline for every step of the way, keeping us on schedule. This detailed calendar allows us to hold each other accountable and maximizes every group member's abilities. All tasks, such as communication with the principal investigator, creating a detailed project plan, ordering materials and more, will be divided amongst the team to increase productivity. Furthermore, we will be assigning leaders for more specific tasks. Responsibly following our schedule will ensure that we complete things on time and it will serve as a checklist. All details on our schedule are expanded upon in our Gantt Chart.

Budget - The $2000 grant will be more than enough to purchase all of the material required to test and launch our experiment. The total cost of our experiment is around $1007.30 leaving approximately $992.70 for resolving any additional costs which may arise. All members of the group will be contacted and must give consent prior to each purchase and a trusted delegate will spend the money. If any money is left over we will either use it to promote our findings or donate it to SHAD. If costs surpass the $2000 stipend we will generate funding through various fundraising efforts.

Conclusion - To conduct our experiment would be only to take a small step. However, in the wise words of Emily Dickenson "one step at a time is all it takes to get you there." Our team has spent the past month researching, planning, and delivering an experiment we believe will lead to much more than a small step for mankind. Invest in our team and we will begin the walk towards a better tomorrow.

Scale Diagram



Payload Requirements Checklist

#	Requirement	Yes	No
1	Payload contains a single autonomous experiment (multiple samples are welcome)	✔	
2	Design is flexible to re-orientation	✔	
3	Teams must build their own 3D-printed box, or order a box with a USB connector	✔	
4	External dimensions of the payload are 4x4x8 inches (~10x10x20 cm)	✔	
5	Total mass of the payload does not exceed 1.1 pounds (500 grams)	✔	
6	If needed, the experiment can operate using 5V of 0.9A power provided via a single USB connector from ~5 minutes before liftoff through ~5 minutes after landing	✔	
7	Payload contains no significant hazards (chemical, biological, stored energy, flammable materials, or radio frequency transmitters)	✔	
8	The payload may contain liquids OR batteries, but not both	✔	
8A	If the payload contains liquids: Up to 5 fl oz or 150 mL of approved non-hazardous liquids are included in two levels of containment	✔	
8B	If the payload contains batteries: Pre-approved small NiMH batteries are used	✔	
9	Payload must be shipped to Texas, USA at least 2 weeks before flight, loaded into the rocket ~4 days before flight, and removed ~8 hours after flight	✔	
10	Experiments may use existing hardware (e.g., Raspberry Pi and Arduino), purchase commercial systems, or develop their own in accordance with the Blue Origin's New Shepard Payload User's Guide. Please describe any existing hardware you will use for your experiment: **Arduino Uno**		

Impact Canvas

Proposal Name: **HMW understand how wounds heal in reduced gravity?(How Osteoclasts/Osteoblasts affect bone remodeling in microgravity**

Experiment Learnings

What do you expect to learn from the experiment?

- We expect to learn the dissolution rate of Hydroxyapatite in HCl under microgravity conditions and will determine if this rate differs from the same reaction on earth. This would also be a step towards discovering how microgravity affects all chemical reactions.
- We will gain insight into the true cause of spaceflight induced osteopenia and will learn whether or not osteoclasts play a key role in causing this condition. Furthermore, our findings will indicate if the imbalance in the ratio between bone repair and bone breakdown (as mediated by osteoblasts and osteoclasts) is due to a change in osteoclast function or if this issue is independent of this cell type
- Our conclusions will affirm or challenge the general consensus which asserts that osteoblasts play the most significant role when it comes to spaceflight induced osteopenia. Obtaining such information will ensure that the path of research with the most potential for finding a solution is pursued.

Applications

What are the industry applications of your learnings?

- Development of enhanced medicine in microgravity
- Increased proficiency in the space industry
- Better healing for athletes/development of medicine for people on Earth
- Commercial space travel(safety for short period)

What specific research gaps will your learnings address?

- Minimal research surrounding osteoclasts has been conducted in space, our experiment would generate never before seen data and work to fill the void of illiteracy when it comes to this cell type
- The difference in the dissolution rates of "bone" dissolving under microgravity and earth conditions will be numerically quantified

What are the other applications for your learnings (ie. policy, marketing etc.)?

- The feat of space travel will become more approachable with medicinal advancements which reduce the risks associated with microgravity Our experiment is a stepping stone for making these advancements realities thereby making space faring more accessible

Stakeholders

What are the specific industries that might benefit from your learnings?

- Space industry
- Commercial Space Travel industry
- Healthcare industry
- Pharmaceutical industry
- Chemical industry

Who are the groups interested in your learnings?

- Groups involved or interested in space travel/advocacy seeing as our findings would help to resolve the unavoidable issue that is bone loss
- Research chemists, if a difference in reaction rate is observed as this would indicate another factor which influences reaction rate exists.

Who else might benefit from your experiment?

- The medical industry may also benefit from the results from the experiment. With the information gained from this experiment, they may be able to create a type of medication to help patients with bone-related diseases such as osteoporosis

Implementation

How might you communicate and disseminate what you learn from the experiment?

- Publishing a research paper
- Publishing numerical data
- Speeches and social events
- Networking
- Documenting our teams journey + findings online (perhaps via social media)

How might you help your stakeholders apply what you have learned?

- communicate our findings to them clearly
- make suggestions as to what our conclusions indicate
- be transparent about the applications which emerge from our experiment as well as their limitations

Who else might benefit from your experiment?

- ISS Space Crew
- Any organism (with bone like structures) who are subjected to microgravity
- Materials scientists/ drug develops who may utilize a changed reaction rate to create products
- Those suffering from osteoporosis and related conditions

Overall Impact

SHORT TERM IMPACT

- Improved understanding of dissolution reactions under microgravity conditions
- Improved and/or better supported explanation for the cause of spaceflight induced osteopenia
- More information generated about osteoclast performance in microgravity
- would shape the path of research and draw attention to the factors which are important regarding bone loss
- open up opportunities for quicker chemical reactions in microgravity

LONG TERM IMPACT

- Possibility for staying longer periods of time in space.
- Negate the risks on bone mass of long term space travel
- increase the amount of time astronauts spend on preserving bone mass and promoting a more efficient usage of time
- Greater potential for space explorations, civilization and societies
- Support of animals in space
- Adaptation not only to microgravity, but possibly to stronger and weaker gravitational forces (ie other planets)
- Development of new medicine to repair/remodel bone structure
- Advanced understanding in bone anatomy

Current Project Budget

#	Name	Price	Quantity	Link	Justification
1	3D Printer Hard Plastic	$119.81	192m	Canadian Tire	To make the box/components
2	Arduino Unos	$53.84	x2	Arduino	To control the experiment
3	Accelerometer	$22.95	x2	Amazon	To measure gravity in box
4	Stepper Motors	$24.27	x5	Amazon	To drive the syringe
5	Threaded Rod	$3.98	x2	Lowe's	To drive the syringe device
6	Screws/Nuts	$16.04	x1	Amazon	To fasten the syringe device
7	Shafts	$8.41	x1	Home Depot	To support the syringe device
8	Motor Coupler	$13.30	x1	Amazon	Connect the motor to the rod
9	Syringes	$24.77	x10	Amazon	To hold the solvent
10	Arduino Kit	$28.17	x1	Amazon	Spare arduino components
11	USB to USB Cable	12.65	x1	Amazon	To power the device
12	Bread Board	$34.03	x1	Amazon	Prototype connections
13	Hydroxyapatite	$472.00*	100g	Sigma Aldrich	To form the bone mimic
14	Acetic Acid	$1.47	4L	Walmart	To act as solvent for bone
15	Stir Bars	$61.00	x10	Stirbars	To agitate the liquid
16	Neodymium Pills	$13.61	x30	Amazon	Component of stir plate
17	Arduino Fans	$17.14	x2	Amazon	Component of stir plate
18	Goretex Membrane	$19.69	0.91m^2	Rockywoods	To let air out but keep liquid in
19	Shipping + Customs	$40.17	N/A	--	Travel to Texas and back
20	Indirect Costs	$20.00	N/A	--	3D Printer Makerspace, Lab use, etc.
Total Budget		**$1007.30**	Amount Granted: **$2000**		*Not including shipping and handling
Amount Excess		**$992.70**			

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Project Plan (Gantt Chart)

	Start Date	End Date	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21
Meet with Principal Investigator (PI) and team	Sept. 1	Oct. 1												
Review the experimental design	Sept. 14	Jan. 11												
Review experiment design with PI	Sept. 14	Dec. 1												
Incorporate and revise design based on team and PI review, create project plan	Sept. 14	Dec. 20												
Order materials and equipment	Dec. 1	Dec. 8												
Receive all shipments(equipment,	Dec. 8	Jan. 11												
Build the experiment	Jan. 11	April 1												
Perform any tests of the experiment	Feb. 1	April 1												
Ship experiment to Texas	April 4	April 28												
Launch of payload	May 1	May 1												
Receive the returned, flown experiment	May 1	May 14												
Perform data analysis	May 15	May 20												
Prepare final write up and share results	May 20	Aug. 1												
Write up results, follow up with PI	May 20	July 1												
Create Presentation and Present at SHAD event	July 1	Aug. 1												

Appendix A

Experimental Design - Expanded

The logistics of our experiment were meticulously discussed to confirm that it was realistic and a feasible evaluation. We precisely measured and calculated all aspects of the experiment so that it would satisfy the Payload Requirements. In an unfamiliar environment such as microgravity, we did not want to overlook the possibility of a fluke. To rule this out, we decided to sacrifice some space in order to fit two samples. The smaller boxes containing the bone and acid will each be 3.81x3.81x3cm, capable of holding 43.5483ml each. The bones are made into flat sheets (2.41x2x1cm) to maximize surface area. In reality, bone loss occurs over a long period and signs are evident after a couple of weeks. In an attempt to make our experiment replicate this, we increased the bone's surface area to encourage a faster dissolution rate. Two plastic clasps (0.7cm long) will be used to hold each bone in place. The bones are held over a mesh separating the 0.13cm magnetic stirrer and the bone. Although the mesh adds to the weight, it is an important component of our experiment as it promotes the homogenization of our solution. Due to the size restraints of the project, our 15cm syringe will have to be placed 2cm into the box. The syringes contain 30ml of acetic acid at 0.50M (31.45%) and are motorized. Given that we will be conducting two trials there will be two identical boxes with two motorized syringes and two identical bone mimics.

To manipulate the syringe, rods would move up and down on a screw. There will be two rods which are attached to an H-nut. This nut will move up and down a screw as the motor turns it and the rods which tightly clasp the plunger (of the syringe) by sandwiching it. The rods will be the same thickness as the gap between the plunger and the syringe when fully compressed. A motorized syringe is necessary to inject and eject the acetic acid at the appropriate time. Once the three minutes are over, the motor will be programmed to turn the screw in the other direction to pull the plunger up. This action will make the syringe collect most of the solution remaining from the reaction. This same solution will later be analyzed upon return to Earth

There are technical and chemical aspects to our experiment so we would be needing softwares such as the Arduino IDE (Integrated Development Environment) and a lab to titrate our results. Technically, we would need an arduino, two fans that are attached to the arduino, two motorized syringe frames, and wires connecting all of them. Chemically, we would need acetic acid and hydroxyapatite. We require plastic clasps to hold the bone, a mesh to keep the magnetic stirrer in place, and the stirrer itself. We need two 30ml syringes as well. Lastly, to build the boxes, we would need a 3D printer. Ideally, we would have a chemist as well as an engineer who are willing to fine-tune and adjust our experiment if needed.

Appendix B

Detailed Gantt Chart

Teams	Team Description
Management team	Organizes teams, assigns and follows upon tasks, sets meetings, contacts resources
Experiment Design Team	Focuses mainly on the design of the experiment
Research Team	Does research, writes up the results, communicates findings
Building Team	Focuses mainly on building and testing the experiment

Project Title: Comparison of Reaction Rate on Earth and in Microgravity (CRREM)

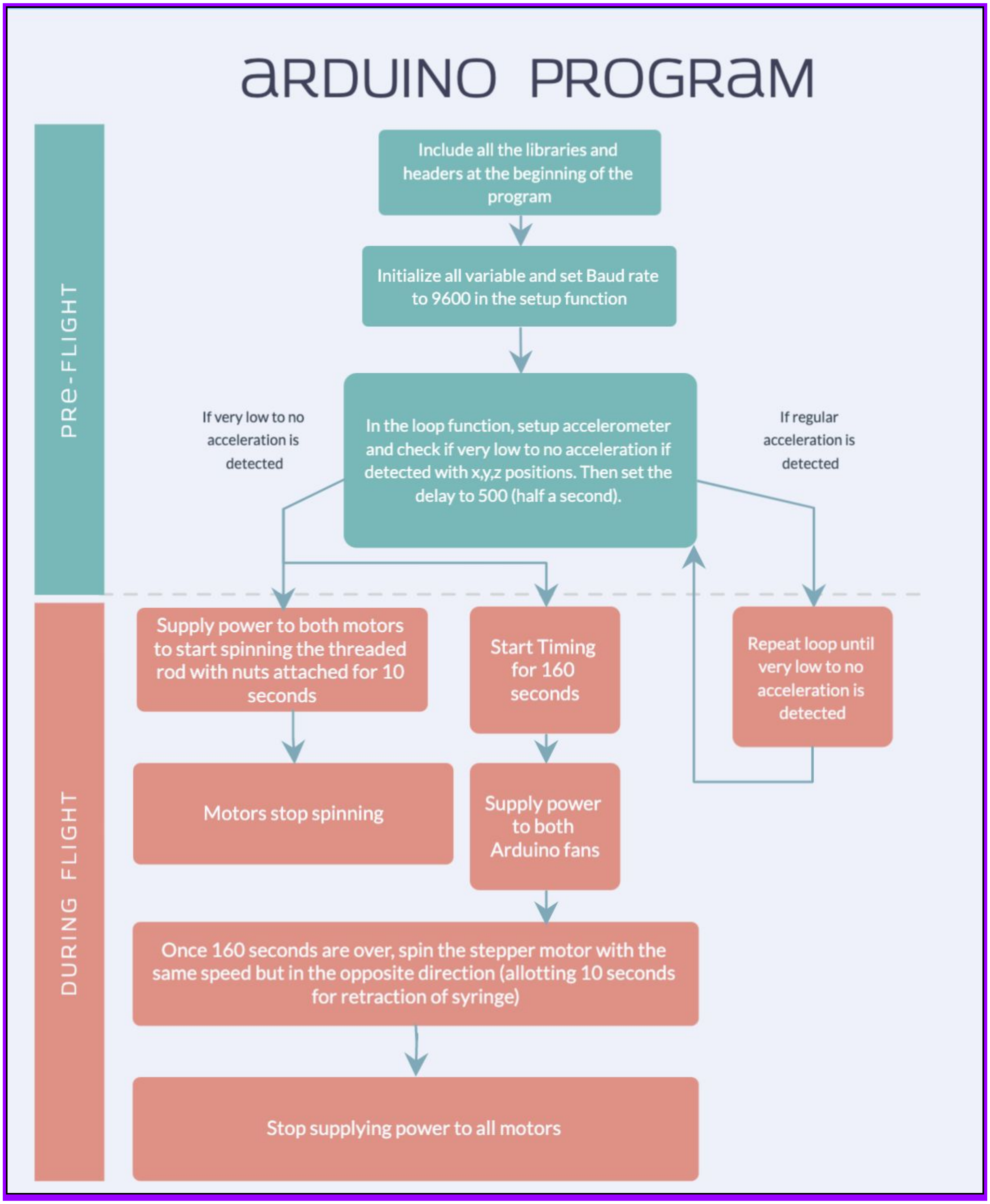
Tasks	Leaders	Do-er	Start Date	End Date	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21
Meet with Principal Investigator (PI) and team			**Sept. 1**	**Oct. 1**												
Kick off: introductions	Whole Team and Principle Investigator		**Sept. 1**	**Sept. 7**												
Set team meeting schedule	Management Team	Whole team	**Sept. 7**	**Sept. 7**												
Review the experimental design	Whole Team		**Sept. 14**	**Dec. 20**												
Incorporate and revise design based on team and PI review	Experiment design team	Whole team	**Sept. 14**	**Dec. 1**												
Create detailed project plan	Management team		**Dec. 1**	**Dec. 20**												
Order materials and equipment	Experiment design team	Management team	**Dec. 1**	**Dec. 8**												
Receive all shipments(equipment, materials, etc.)	Experiment design team	Management	**Dec. 8**	**Jan. 11**												
Build the experiment	Building team	Whole team	**Jan. 11**	**April 1**												
Perform any tests of the experiment	Building and Experiment		**Feb. 1**	**April 1**												

Project Title: Comparison of Reaction Rate on Earth and in Microgravity (CRREM)

Tasks	Leaders	Do-er	Start Date	End Date	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21
Pack experiment into payload	Building team and Experiment design		**April 1**	**April 3**												
Ship experiment to Texas	Management team		**April 4**	**April 28**												
Launch of payload	Blue Origin		**May 1**	**May 1**												
Receive the returned, flown experiment	Management team		**May 1**	**May 14**												
Perform data analysis	Research team		**May 15**	**May 20**												
Prepare final write up and share results	Research team	Whole team	**May 20**	**Aug. 1**												
Write up results	Research team	Whole team	**May 20**	**July 1**												
Follow up with Principle Investigators (questions, etc.)	Experiment design team	Whole team	**May 20**	**July 1**												
Create Presentation	Research team	Whole team	**July 1**	**Aug. 1**												
Present at Shad event (TBD)	Whole team		**Aug. 1**	**Aug. 1**												

Appendix C

Arduino Flow Chart



Appendix D

Resources

What happens to bones in space? - Canadian Space Agency
A systematic review and meta-analysis of bone loss in space travelers
Bone Density Decreases in Space - What to Do? | Video
Creating Artificial Bones for Faster Bone Regeneration | Research Stories | Research | Tokyo Institute of Technology
BASIC REACTIONS OF OSTEOBLASTS ON STRUCTURED MATERIAL SURFACES
Space Bones | Science Mission Directorate
Q & A: How do osteoclasts resorb bone?
Q & A: How are osteoclasts formed?
A Novel Small Molecule Which Increases Osteoprotegerin Expression and Protects Against Ovariectomy-Related Bone Loss in Rats
The Musculo-Skeletal System in Space
Bones in Space
Random42 Medical Animation - Osteoblasts and Osteoclasts
Osteoclast: Definition, Function & Formation - Video & Lesson Transcript
In vitro Models of Bone Remodelling and Associated Disorders
settings Open AccessArticle Recombinant Irisin Prevents the Reduction of Osteoblast Differentiation Induced by Stimulated Microgravity through Increasing β-Catenin Expression
Osteoblasts in Bone Physiology—Mini Review
Researchers to Test How Solids Dissolve in Space
Effects of microgravity on osteoblast growth
Microgravity induces inhibition of osteoblastic differentiation and mineralization through abrogating primary cilia
Microgravity induces inhibition of osteoblastic differentiation and mineralization through abrogating primary cilia
Osteoblasts and Osteoclasts
Bone Remodeling and Modeling
Acid phosphatases
Astronaut Bone Loss
What Happens to Our Bones When We Exercise? | The Evidence Exercise | Episode 5
Stress Effects on the Body
Bone
Bone Cells
Bone Lining Cell - an overview

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Bone and Muscle Loss in Microgravity
Osteoblast-Osteoclast Interactions
Effects of microgravity on osteoclast bone resorption and osteoblast cytoskeletal organization and adhesion
Gene Expression in Osteoblasts and Osteoclasts Under Microgravity Conditions: A Systematic Review:
Biomaterial scaffolds for treating osteoporotic bone
Material bones up
Osteoclast differentiation induced by synthetic octacalcium phosphate through receptor activator of NF-kappaB ligand expression in osteoblasts
Microgravity induces inhibition of osteoblastic differentiation and mineralization through abrogating primary cilia
The Impact of Simulated and Real Microgravity on Bone Cells and Mesenchymal Stem Cells
The roles of integrins and MAPK signaling pathways in the osteoinduction of biphasic calcium phosphate
Simulated microgravity suppresses osteoblast phenotype, Runx2 levels and AP-1 transactivation
Effects of microgravity on osteoblast mitochondria: a proteomic and metabolomics profile
The effect of simulated microgravity on osteoblasts is independent of the induction of apoptosis
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Bones in Space
Q & A: How do osteoclasts resorb bone?
Effects of microgravity on osteoclast bone resorption and osteoblast cytoskeletal organization and adhesion
Microgravity promotes osteoclast activity in medaka fish reared at the international space station
Bendy Bones
The effects of acid on bone