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MIT Zero-G outreach initiative: Using experiment design and virtual reality to inspire the next generation of space scientists and engineers

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ABSTRACT

MIT's Space Exploration Initiative offers a course on project development, prototyping, and deployment readiness for parabolic flights, culminating in an annually chartered research flight with Zero-G. MIT's Resource Exploration and Science of our Cosmic Environment (RESOURCE) team participated in the course in the fall of 2021 with a Zero-G flight in May of 2022 testing technology for a virtual reality platform to enable science on Lunar rover exploration missions. In parallel with the scientific effort, the team developed the MIT Zero-G Outreach Initiative (0G-OI), an outreach program to engage with the Cambridge Public School's (CPS) grade 7 classes to teach them about research in microgravity, parabolic flight, and experiment design. The goal of the outreach program is to inspire the next generation of space scientists and engineers using virtual reality.

The CPS grade 7 curriculum covers 'Mysteries of the Universe' where students consider the role of gravity in the solar system. They also complete a unit on roller coasters in which they learn about key ideas of force, motion, and energy through the context of roller coasters. The 0G-OI Initiative ties these two units together through five videos covering: 1) an overview of the initiative, 2) the basics of parabolic flight and how we perceive gravity, 3) an overview of gravity and its function in the universe, 4) why and what we can study in microgravity and 5) how to design an experiment for microgravity. The students then design their own experiments for microgravity. These are down-selected to the top 5 experiments that are reviewed by an astronaut to select one experiment to fly on the MIT chartered Zero-G parabolic flight. The flight and the experiment are filmed in VR video by the MIT RESOURCE team. Each participating school is provided with an Oculus Quest 2 VR headset and a flight day is held at each school where the students experience the Zero-G flight and see the results of their experiment in an immersive VR environment. Using this initial setup, the 0G-OI can be run annually in parallel with MIT's SEI parabolic flight course.

Some key development parameters included keeping the educational videos under 10 min, that having an astronaut select the winning experiment provided incentive and finally, using VR, as this technology is commonly associated with gaming and entertainment. Lessons learned focused on improvements to scheduling and coordination with Zero-G, in-person programming and classroom experience optimization. The 0G-OI aims to develop a lasting relationship with the CPSs and make the exciting experience of parabolic flight and space exploration an accessible experience.

1. Introduction

Virtual reality is an exciting technology which has gained traction both in the entertainment industry and as a tool for space applications in recent years. The Mars Curiosity Rover team used VR to explore geological sites on Mars [1]; NASA uses VR for both astronaut training [2] and as an outreach tool; the entertainment industry has developed immersive games such as Mission ISS for the Oculus Quest. Additionally, there are numerous analogue missions developing VR tools for mission

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Acronyms/abbreviations

0G-OI	Zero-G Outreach Initiative
CPS	Cambridge Public Schools
FAA	Federal Aviation Administration
ISRU	In situ resource utilization
MIT	Massachusetts Institute of Technology
NASA	National Aeronautics and Space Administration
RESOURCE	Resource Exploration and Science of our Cosmic Environment
SEI	Space Exploration Initiative
VR	Virtual reality

operations, be it human or robotic [3]. MIT's Resource Exploration and Science of our Cosmic Environment (RESOURCE) team, funded by NASA's SSERVI (Solar System Exploration Research Virtual Institute), informs future in situ resource utilization (ISRU) through the scientific investigation of potential resources on SSERVI Target Bodies, and the development of operations and hardware associated with ISRU prospecting. The MIT branch of the RESOURCE team fsocuses on operations and associated technologies for optimizing human interaction with robotic explorers. A key development in this research is developing a VR platform which can provide naturalistic visualization tools that multiple team members can use to analyse, discuss, and interpret data, giving the potential to dramatically improve scientific return on both rover prospecting missions, and later human exploration missions [4–6].

The RESOURCE team also focuses on how these tools can help to make space more accessible, not only to scientists currently involved in space exploration, but to inspire future generations to follow this path as well [7]. VR is already prominently featured in the entertainment industry and is becoming a useful tool for education [8–11] and training [2,12,13].The MIT Zero-G Outreach Initiative (0G-OI) seeks to use VR to create a real-world experience for Grade 7 students in the Cambridge Public Schools (CPS) to design and execute a microgravity experiment and view the Zero-G flight with the results in VR. In doing so, the OG-OI hopes to inspire the next generation of space explorers and engineers.

As part of the VR development work, two students from the RESOURCE project took MIT's Space Exploration Initiative (SEI) course, *Prototyping our Sci-Fi Space Future: Designing & Deploying Projects for Zero Gravity Flights*, a course on project development, prototyping, and deployment readiness for parabolic flights, culminating in a research flight with Zero-G. During the class the 0G-OI was developed, an outreach project with the aim to share the Zero-G research flight experience with CPS students.

Using a series of short videos two of the CPS science units, Mysteries of the Universe, and Rollercoasters, were tied together to give students the knowledge needed to design their own microgravity experiment with the guidance of the MIT RESOURCE team. These were down-selected to the top 5 experiments that were then built by the students and reviewed by astronaut Dr. Jeff Hoffman who selected one experiment to fly on the MIT chartered Zero-G parabolic flight.

The flight and the students' experiment were then recorded in VR video. Each of the classes involved were provided with two Oculus Quest 2 VR headsets and a demonstration day was held at each school where the students were able to experience the Zero-G flight and see the results of their experiment in an immersive VR environment.

This program was run with two schools in the CPS system, with a total of seven Grade 7 classes.

2. Program design

Based on the guidance of the CPS Science Coordinators, the program focused on Grade 7 students. Their curriculum most closely aligned with the content of the outreach program with a high enough level of knowledge that would enable them to actively participate in the design of a microgravity experiment. Here we outline the overall program schedule, the methodology for designing the outreach educational content, the experimental design procedures, and the experiment selection process and criteria. Finally, the methodology for the virtual reality content creation and demonstration day are described.

2.1. Program schedule

The outreach program was developed during the fall semester of 2021 as part of SEI's course. The program was developed based on the Grade 7's curriculum as well as the deadlines provided by Zero-G for flight requirements. Fig. 1 shows the timeline of events highlighting deliverables and deadlines for Zero-G.

The CPS Grade 7 curriculum includes two relevant units: 1) Mysteries of the Universe and 2) Rollercoasters. The Mysteries of the Universe unit covers the role of gravity, the patterns and forces of the Sun, Earth, and Moon system applicable throughout the universe, and the role of gravity in the solar system and the factors that affect it, for instance how the planets are formed. The key concepts in the Rollercoasters unit are ideas of force, motion, and energy through the context of roller coasters measuring motion via distance and time graphs, forces that cause motion, and where the energy comes from to make things move. The students examine the relationships between force, motion and energy and are asked to figure out Newton's Laws of Motion on their own. The two units are taught in January and February of the winter semester. We aligned our educational videos with these two units to tie in the concepts they were learning in class to what they would need to know to develop their own microgravity experiment for a parabolic flight.

After the students were shown the videos, they were provided with guidance on designing their own experiments as well as a Payload Proposal document developed by the 0G-OI. They were given one month to design their experiments and submit their proposal documents. The details of the experimental design and the proposal document are described in Section 2.3. The students were also given access to the graduate students on the project to ask questions.

The graduate students then took one week to select the top five experiments that would be provided with all the tools and equipment necessary to build their experiments. The selection process is described in Section 2.4. Supplies were purchased and organized for each experiment and delivered to the schools. Once the students had their supplies, they were asked to build their experiments within two weeks. These were then shown to astronaut Dr. Jeff Hoffman (as described in Section 2.4) who subsequently took 3 days to select the top experiments for flight. 2 weeks were permitted to obtain permission to fly one of the experiments on the Zero-G flight. This was insufficient time to satisfy the flight requirements for the top experiment (discussed in Section 5, Lessons Learned), however, the secondary selection was granted permission the day prior to the flight.

2.2. Educational content

The 0G-OI focused on three main themes: microgravity, parabolic flight, and experimental design. To introduce these concepts to the CPS Grade 7 students a series of short educational videos were developed. These included: 1) an overview of the initiative, 2) the basics of parabolic flight and how we perceive gravity, 3) an overview of gravity and its function in the universe, 4) why and what we can study in microgravity and 5) how to design an experiment for microgravity. The videos were designed to tie in with the CPS Grade 7 units: Mysteries of the Universe, and Rollercoasters. Fig. 2 shows example stills from each lesson's video. The content was created by author C. Paige in collaboration with the CPS science coordinators using the CPS curriculum outlines and requirements for the units focusing on concepts directly

TASK	START	END
Develop curriculum	9-28-21	10-19-21
Develop schedule	9-28-21	10-19-21
Apply for funding	9-14-21	9-21-21
Funding results	9-21-21	10-5-21
Record educational videos	10-19-21	11-9-21
Deployment		
CPS curriculum units	1-5-22	3-6-22
Educational videos shown to students	3-6-22	3-13-22
Provide Payload Package to students	3-13-22	3-14-22
Student experiment development	3-14-22	4-11-22
Round 1 down-selection (top 5)	4-11-22	4-18-22
Student experiment build	4-18-22	5-2-22
Astronaut presentation	5-2-22	5-2-22
Round 2 down-selection (top 2)	5-2-22	5-5-22
FAA approval with Zero-G	5-5-22	5-19-22
Flight Day (Zero-G)	5-20-22	5-20-22
Demonstration Day	6-16-22	6-16-22

Fig. 1. Schedule of MIT Zero-G Outreach Initiative development and deployment.

related to the outreach initiative. All the videos are available online on the 0G-OI YouTube channel.

The videos are kept under 10 min and use visual aids to easily demonstrate the scientific concepts. Here we give a brief description of the concepts covered by each video.

2.2.1. *Lesson 0: introduction*

The first video, Lesson 0, introduces the 0G-OI and its goals, Fig. 2 – L0. The video introduces the MIT graduate student teaching the lessons focusing on her career path and in particular demonstrating how career paths can change, and the many ways one can find their way in a career in Science, Technology, Engineering, Art, Mathematics and Design (STEAMD). The video introduces the concepts that will be covered – parabolic flight, the MIT Zero-G flight, microgravity experimentation and the students' involvement in the Zero-G initiative. A short video is shown of a Zero-G flight from a previous year.

2.2.2. *Lesson 1: parabolic flight*

The second video, Lesson 1, gives a brief introduction to what gravity is as a force, and how we can change how we experience gravity using reactionary forces and inertia, Fig. 2 – L1. The video relates this experienced gravity to roller coasters and defines these effects in terms of parabolic shape. Microgravity, hyper-gravity, and reduced gravity are defined in terms of the parabolic flight path. Force balance is also used to describe why falling inside of an airplane feels different than free-falling through atmosphere, like skydiving.

2.2.3. *Lesson 2: gravity*

This high-level introduction to gravity, Lesson 2, uses a video to demonstrate how different masses exert different amounts of gravity and how an initial force on an object will cause an object to go into orbit around an object of greater mass, Fig. 2 – L2. The concept of orbital dynamics and escape velocities are introduced and how an object transitions between two gravitational forces. Thrust is also described in

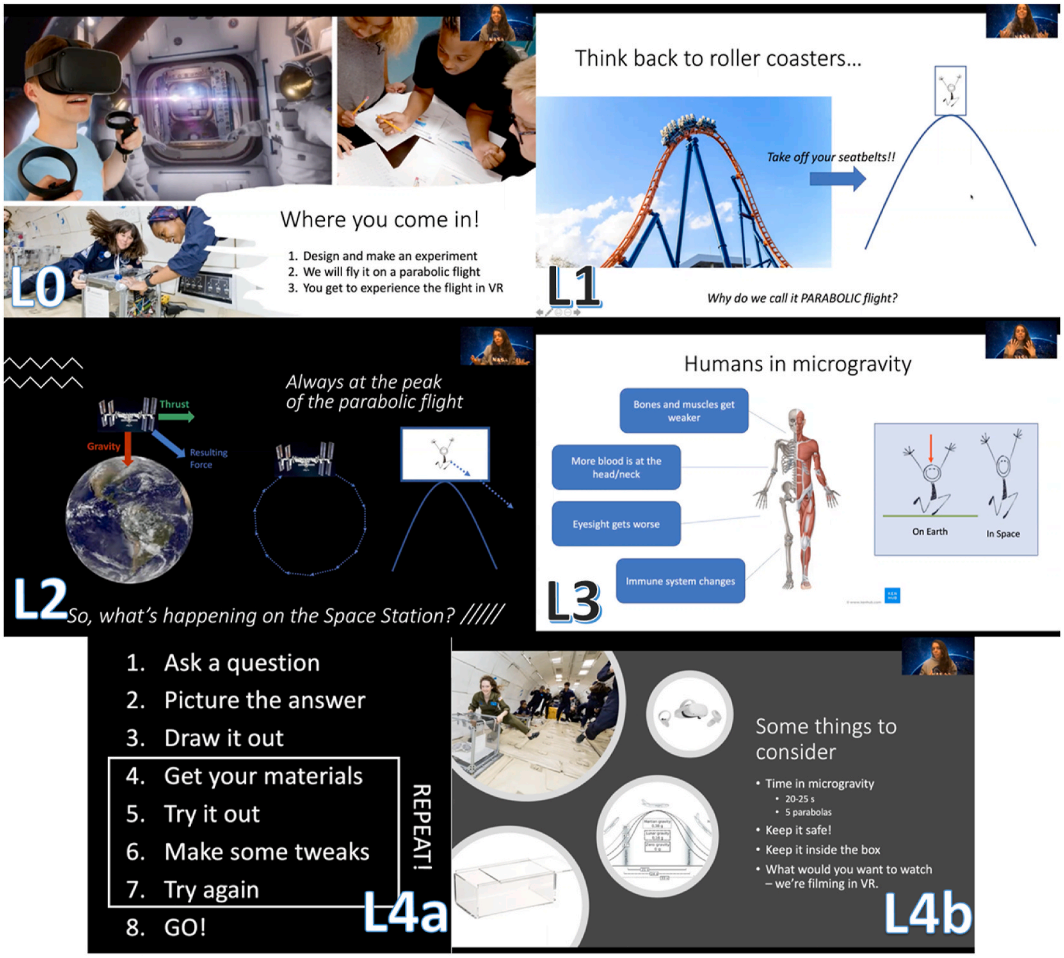

Fig. 2. L0 - Lesson 0: Introduction, showing C. Paige in top right corner, Top Left: sample of VR use in a space application (VR game, Mission ISS), Bottom Left: Astronaut Cady Coleman and an MIT student on a previous MIT SEI Zero-G flight, Top Right: students working on experiment design and Bottom Right: Goals for CPS students for the MIT Zero-G Outreach Initiative. L1 - Lesson 1: Parabolic Flight, showing C. Paige in top right corner and demonstration of how rollercoaster dynamics translates to parabolic flight. L2 - Lesson 2: Gravity, showing C. Paige in top right corner and demonstration of how we perceive gravity in space and how it relates to parabolic flight. L3 - Lesson 3: Why study in Microgravity, showing C. Paige in top right corner and slide explaining the impacts of prolonged microgravity on the human body. L4a - Experimental design procedure outlined in Lesson 4. L4b - Lesson 4: Designing your Zero-G experiment, showing C. Paige in top right corner and slide explaining considerations for student experiment design.

the context of manoeuvring spacecraft.

2.2.4. Lesson 3: why study in microgravity

First the video introduces planet formation and the role of gravity in the solar system. The focus then shifts to the impact of microgravity on the body: bone elongation, blood pooling, eyeball pressure and vision, Fig. 2 – L3. They then describe how the dominating force on liquids is surface tension when in microgravity and two NASA videos are used to demonstrate what this looks like on the space station. Finally, different microgravity experiments are introduced to provide the students with ideas for their own experimental design.

2.2.5. Lesson 4: designing your Zero-G experiment

The experimental design process is described in terms of basic steps, Fig. 2 – L4a. The rules are then outlined for the MIT Zero-G flight. These rules are designed to simplify the Federal Aviation Administration (FAA) approval process. Finally, concepts to consider for a successful experiment are outlined including time spent in microgravity, safety considerations, and considerations for observing the experiment (students will only be observing their experiment in virtual reality, so a visually interesting experiment would be more likely to succeed, Fig. 2 – L4b. Because only one experiment was able to fly on the Zero-G flight, the video also outlines the criteria that will be used to select the top experiment.

The videos were shown to the students after the two associated CPS curriculum units had been completed.

2.3. Experimental design

To facilitate the students' experimental design, a Payload Proposal document was created. This document was designed as a simplified version of the MIT SEI course's payload proposal document that is required by Zero-G for experiment payloads. The document provides students with a brief description of the project and what is expected of them, the rules they are required to follow, and contact information for any questions they have. The rules outlined for the students are as follows.

- It needs to be passive – can't be plugged in or use batteries and can't need someone to operate it. However, it can be shaken or tipped, we just can't open it during flight.
- AA and AAA batteries are allowed
- It needs to fit inside a clear shoe-box size box (approx. 12.5″ x 8.5″ x 8.5″) which will be provided to you.
- No liquids unless they are doubly contained (ex: liquid is inside a water bottle inside the box)

- Liquids must be less than 100 mL and must be skin safe or edible/drinkable
- You'll only have 20–25 s in microgravity per parabola and 5 parabolas so make sure your experiment is quick enough to see results in 20 s.
- Budget: your total cost for your experiment must be $100 or less.
- Keep it safe! Think through if it might be dangerous in any way
- What would you want to watch in virtual reality? Try to make it visually interesting.

They are then provided with space to fill in their project details. They are asked for a project description; name, team, overview, scientific question, hypothesis and expected results. Next, they are asked for the details of their project; design (sketch), method of operation (how the experiment will work), an equipment list and budget. Finally, the students are asked to identify any risks or hazards they foresee with their experiment.

2.4. Experiment selection process

The selection process was conducted in two stages. The students first submitted their Payload Proposal documents to the MIT graduate students. The documents were reviewed and divided into categories; interestingly students came up with similar experimental designs, for example 'how magnets work in microgravity' and 'how liquids mix in microgravity'. Experiments were eliminated if they did not follow the rules or if the document was incomplete. The top five experiments were selected based on the following criteria.

1. Scientific merit – is the question well thought out and does it have a reasonable hypothesis.
2. Feasibility – does the experiment follow the criteria and the rules set out for the flight and is the complexity something reasonable for the given timeframe.
3. Expected results – do the expected results match the mission goals, i.e., to provide an interesting visual experiment for VR viewing

Because there were only two schools participating and it was important to maintain involvement with both schools, at least one experiment from each school was selected to remain in the top five.

The supplies for each of the five experiments were purchased using the MIT COOP grant and organized according to experiment. These were delivered to the schools for the students to build.

The students then demonstrated their built experiments during a 'Meet an Astronaut' video call to astronaut Dr. Jeff Hoffman. The call also included a short presentation by Dr. Hoffman on what it's like to work in microgravity and his experience on both the shuttle and Zero-G flights. He shared his experience with experimentation in microgravity and answered students' questions. The winning experiment was selected by Dr. Hoffman based on the same criteria listed above as well as their demonstrations.

Two projects were selected as the top team had a very complicated design and it was not certain that Zero-G would approve the experiment for flight. The first-choice experiment, Fig. 3 – Left, mixed acetic acid with baking soda to produce CO_2. The experiment used light activated Arduino pumps which were activated by removing small light shields on the outside of the box. One of the main reasons this was selected was that seeing the behaviour of the CO_2 bubbles in microgravity would be interesting and visually suitable for VR. The concern with this experiment was that there was a lot of plumbing required, and the team needed to pump fluid within the sealed container. There were also exposed wires which was a cause for concern.

The second choice was an oil and water experiment, Fig. 3 – Right, It was not a novel experiment but was still visually interesting. A secondary question of interest was how long it takes the oil and water to separate in hyper-gravity after being shaken compared to Earth gravity.

2.5. Virtual reality

To prepare for the virtual reality demonstration, two Oculus Quest 2 headsets were purchased for each classroom using the MIT COOP grant. Additionally, an Insta 360 One X VR camera was procured from the MIT Human Systems Lab to record the flight and experiment.

3. Parabolic flight and recording

On May 19th, the day prior to the MIT Zero-G flight day, the experiments were brought to the Zero-G hangar in Portsmouth, New Hampshire. Both experiments were shown to the Zero-G flight team to assess their flight readiness. Unfortunately, due to the wiring and complicated nature of the CO_2 experiment it was not permitted to fly (see Lessons Learned for how this could have been avoided). The oil and water experiment was permitted with the exception that the liquids be mixed by the flight crew on the day of the flight.

On May 20th, the day of the flight, the oil and water experiment was stored in a bin on the aircraft. The first 5 parabolas of the flight were in Martian and Lunar gravity, the experiment remained in storage for these parabolas. During the 1-g period between parabola sets the experiment was retrieved from storage and held by an MIT graduate student to do the demonstration throughout the next 5 parabolas. The flight path is shown in Fig. 4 with the microgravity parabolas marked as Zero Gravity.

The Insta 360 One X was used to record both the microgravity and hyper-gravity portions of the parabolas. The experiment was shown in the following configurations.

1. Shaken
2. Spun
3. Free-floating

Fig. 3. Left - Top-choice experiment selected by astronaut Jeff Hoffman – acetic acid mixing with baking soda to produce CO_2. Right - Second-choice experiment selected by astronaut Jeff Hoffman – mixing of oil and water.

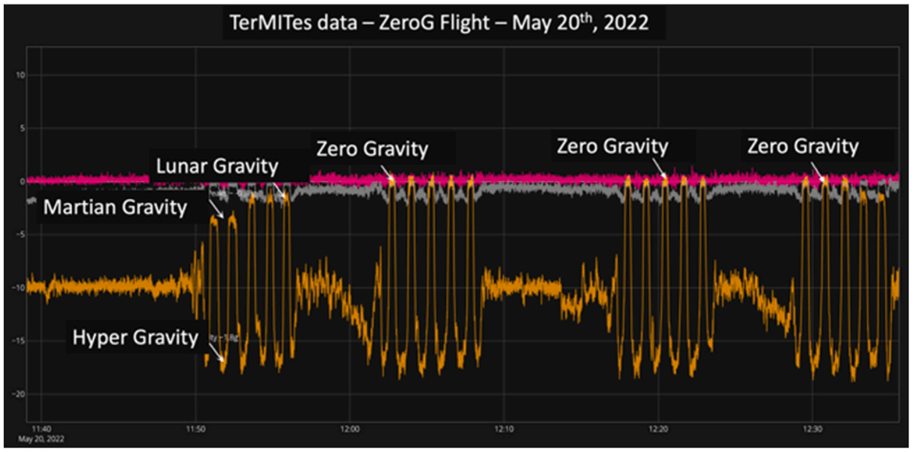

Fig. 4. Zero-G flight data from the TerMITes project for May 20th, 2022. Martian, Lunar, Zero and Hyper gravity labelled per the gravity of the associated parabolas.

The hyper-gravity component was recorded as well to demonstrate the speed of liquid separation compared to 1-g. A still from the recording is shown in Fig. 5.

The recordings were then edited and uploaded onto a dedicated YouTube playlist. Two primary videos were selected to show the students the results of their experiment during the Demonstration Day.

4. Demonstration day

Demonstration days were planned with each school to provide all the classes with 45 min to share the Zero-G flight experience, discuss the results of their experiment, and explore other MIT experiments that have flown on Zero-G flights and on the International Space Station.

During each demonstration, a brief introduction was given to the students to describe the procedures of the parabolic flight, give a personal description of the experience, and recap the key concepts covered in the educational content, Fig. 6.

Along with the class owned Oculus Quest 2 headsets, 2 additional headsets were brought to each class to maximize VR time for the students. Each student was given the opportunity to watch a 1-min video of the Zero-G flight which showed the experiment being rotated in microgravity and the liquids settling in hyper-gravity. To maintain a safe space for the students, the VR was viewed while seated and students were advised to make only slow movements with their heads and to remove the headsets if they experienced any discomfort as VR can cause nausea.

Three MIT experiments were brought to the classrooms for the students to explore as well. These included.

1 The MIT SkinSuit – an elasticized suit worn in microgravity to minimize bone loss and muscle deterioration.
2 The MIT BioSuit breathing bladder – a bladder made to ease breathing when wearing the BioSuit, a mechanical counterpressure spacesuit.
3 A LiDAR camera mounted to a mini rover for depth data collection on the Lunar surface.

Students were able to interact with the MIT experiments, ask questions to the MIT graduate students, and explore the Zero-G experience in VR. Fig. 6 shows the VR demonstration, Fig. 6, bottom, shows the introduction being given by C. Paige (left) and F. Ward (right), Fig. 6, top left, shows students experiencing the Zero-G flight in VR and Fig. 6,

Fig. 5. Zero-G flight with student experiment being operated by C. Paige (green jumpsuit) and recorded by F. Ward (centre). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Fig. 6. Top left - students immersed in VR. Top right - Students interacting with the MIT microgravity experiments. Bottom - MIT graduate students introducing Demo Day.

top right, shows students interacting with the MIT experiments.

5. Lessons Learned

Given this was the first year the 0G-OI was run, there were multiple challenges that could be avoided in future years which are outlined here, as well as successes that should be highlighted.

Tying the educational content to the curriculum was a key aspect in deployment since it enabled teachers to embed the program into the current curriculum without the need for additional approvals or content creation on their part. Additionally, it could be conducted as part of the students' scheduled classwork ensuring participation from all students without dependency on cost, parent availability or student after-hours availability. This is critical for diversity and inclusion of participants both from a financial standpoint and to encourage all aspects of STEAMD (Science, Technology, Engineering, Art, Math and Design) thinking.

The most prominent challenge was in scheduling. The MIT SEI course ran from September 2021 to December 2021which meant the final schedule for the 0G-OI was not completed until the end of the course. The videos were not ready to show the students until February 2022 which pushed the experiment delivery schedule out until the end of April. Zero-G requires a minimum of 4 weeks to get approval from the FAA for experiments onboard the flight and with only 2 weeks of notice for the student experiments, the top choice experiment was denied flight approval. In future years the videos would need to be shown to students at the end of January to allow for enough time for the remaining scheduled activities. This would put the videos between the two associated CPS units which would be ideal for introducing the scientific concepts and allowing students enough time to design their experiments.

The video call with the astronaut could also have been scheduled in a more interactive manner. If planned with more time, a panel of astronauts could have been organized to provide additional interaction with the students. As well, as activities return to being in-person as a standard, it would be ideal to have the astronaut presentations be organized in-person with each school. This would provide a more tangible experience for the students and allow a more informal atmosphere to ask questions and interact with the astronauts.

Finally, the demonstration day would be ideally suited to having a half-day event for each school where all the classes from that school could be present for the full time and additional MIT students would need to be available to answer questions. While the in-class demonstrations did allow enough time for each student to view the flight in VR, the MIT students spent the time aiding the Grade 7s with the VR headset and did not have the additional capacity to answer questions and demo the MIT experiments. The additional MIT students would allow for more interaction and having the half-day with all classes combined would provide a more hands-on style experience. Students would feel like they could explore the MIT experiments more confidently and would have time to think of questions. Additionally, students could take more time in the VR environment, and come back to specific videos of the flight that they wanted to revisit.

6. Conclusion

The MIT Zero-G Outreach Initiative was designed in collaboration with the Cambridge Public School board and the teachers involved to provide an engaging and inspiring curriculum to teach students about working in space and experimental design. Students were taught about the basics of parabolic flight and how we perceive gravity, the function of gravity in the universe, why and what we can study in microgravity, and how to design an experiment for microgravity. These topics built on the pre-existing grade 7 curriculum topics of Mysteries of the Universe and Rollercoasters to ensure a seamless integration and ease of course load for the teachers. Students were then guided in designing their own experiments for a parabolic flight which they presented for selection by astronaut Jeff Hoffman. The winning experiment was flown on the chartered MIT Zero-G scientific flight in May of 2022 and recorded in VR video. The students were then given the opportunity to experience the flight for themselves in VR, observing the winning student experiment in microgravity. They were also shown experiments designed and flown by MIT students. The content and methodology developed for this initiative were used again the following year (2023) and are now established for a continued relationship between MIT and the Cambridge Public Schools. This program can be expanded to other public schools in the great Boston area with potential for growth beyond this region. By incorporating this program directly into the curriculum, it provides an equal opportunity for students to participate in an engaging activity, inspiring an interest in STEAMD careers. MIT 0G-OI also demonstrates the benefits of building relationships between early- and higher-education.

7. Future work with CPS students

Overall, this was a positive experience for both the MIT graduate students and the CPS Grade 7 classes. Students expressed excitement about the opportunity both to work on science projects that would be in microgravity as well as getting the VR experience. The teachers involved provided feedback stating they would like to continue working with the MIT Zero-G initiative, encouraging the improvements listed in the Lessons Learned Section. The goal of the 0G-OI was to inspire students in the field of STEAMD using VR and to provide a real-world experience for the experimental design knowledge they have learned in their classrooms. These goals were achieved and provided the Grade 7 classes with continued access to both the Zero-G flight in VR and to other VR experiences that can provide access to scientific exploration using their in-class Oculus Quest 2 headsets. Future years of the 0G-OI will fortify the relationship between the CPS and MIT and provide access to students to space exploration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] G. Caravaca, S. Le Mouilic, N. Mangold, J. L'Haridon, L. Le Deit, M. Masse, 3D digital outcrop model reconstruction of the kimberley outcrop (gale crater, Mars) and it's integration into virtual reality for simulated geological analysis, Planet. Space Sci. 182 (2019), https://doi.org/10.1016/j.pss.2019.104808.

[2] A.D. Garcia, J. Schlueter, E. Paddock, Training astronauts using hardware-in-the-loop simulations and virtual reality, AIAA Scitech 2020 Forum 1 (2020) 1–13, https://doi.org/10.2514/6.2020-0167. PartF, no. January.

[3] D.S.S. Lim, et al., The BASALT research program: designing and developing mission elements in support of human scientific exploration of Mars, Astrobiology 19 (3) (2019) 245–259, https://doi.org/10.1089/ast.2018.1869.

[4] C. A Paige, et al., Development and testing of the concept of operations for a low-cost RGB and depth-camera for a lunar south Pole mission, Nat. Microgravity, (2023) (in prep).

[5] C.A. Paige, et al., "Data collection in Svalbard, Norway to test the use of virtual reality for Lunar and planetary surface exploration,", in International Conference on Environmental Systems (2023) 362.

[6] C.A. Paige, et al., Operational Geology in a Virtual Environment (OGIVE) Novel Approaches to Virtualizing, Geological Expeditions for Planetary Exploration, 2023.

[7] M.R.A. Moreno, C.A. Paige, J. Stober, J. Rupasinghe, D. Wood, D. Newman, Capturing the Moon: 3D Mapping and Regolith Collection for Low-Cost Lunar Rover Missions,, 2022, https://doi.org/10.2514/6.2022-4285.

[8] J. Pirker, A. Dengel, The potential of 360 virtual reality videos and real VR for education - a literature review, IEEE Comput. Graph. Appl. 41 (4) (2021) 76–89.

[9] M. Sattar, S. Palaniappan, A. Lokman, N. Shah, U. Khalid, R. Hasan, Motivating medical students using virtual reality based education, Int. J. Emerg. Technol. Learn. 15 (2) (2020) 160–174.

[10] M. Soliman, A. Pesyridis, D. Dalaymani-Zad, M. Gronfula, M. Kourmpetis, The application of virtual reality in engieering education, Appl. Sci. 11 (6) (2021) 2879.

[11] M. Janiszewski, L. Uotinen, J. Merkel, J. Leveinen, M. Rinne, Virtual Reality learning environments for rock engineering, geology and mining education, in: *54th* U.S. Rock Mechanics/Geomechanics Symposium, ARMA, 2020, pp. 20–1101.

[12] V.H. Andaluz, et al., Oil processes VR training, in: Advances in Visual Computing: 13th International Symposium, ISVC, 2018, pp. 712–724.

[13] B. Xie, et al., A review on virtual reality skill training applications, Front. Virtual Real. 2 (2021), 645153.