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THE SPHERES ZERO ROBOTICS PROGRAM: EDUCATION USING GAMES

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Abstract: Zero Robotics (ZR) is a robotics programming competition school where students write programs that control a satellite in space, all from a web browser. The robots are miniature satellites called SPHERES – an experimental test bed developed by the MIT SSL on the International Space Station (ISS) to test control and navigation algorithms in microgravity. The participants compete to win a technically challenging game by programming their strategies into the SPHERES satellites. The programs are demonstrated first on the ground hardware and then in a final competition when an astronaut runs the student software aboard the ISS. ZR had a "Pilot" event in 2009 with ten High School students, a nationwide pilot tournament in 2010 with over 200 High School students from 19 US states, and a summer tournament in 2010 with ~150 middle school students. The tournaments in 2011-2012 are part of the DARPA InSPIRE program has over 1000 students and is supported by NASA and Aurora Flight Sciences. The entire software framework for the program is being built in collaboration with TopCoder, utilizing crowdsourcing contests within their community of 250,000 developers. In contrast to the neck-to-neck competition in the previous tournaments, the 2011 tournament endorses collaborative competition. Autonomous cooperation during the game is incentivized - players that control the SPHERES can score more points if they collaborate with their opponents to achieve the game objectives. Teams will also be required to form alliances and work together to submit an integrated project to control the SPHERES. Metrics of ZR performance have been student participation, demographic data, response to surveys during and after tournaments, dominating player strategies during competitions, results of the competitions, return of teams in a subsequent year to participate again and other such trends. This paper discusses the lessons learned in ZR on the topics of game design, tournament organization and STEM outreach and how these lessons have helped us improve the educational value delivered by ZR.

I. INTRODUCTION

Space has often been considered a hobby of the intellectual elite and rarely looked upon as a perfect and accessible laboratory environment to see the science equations in textbooks come alive. It is to dispense with this myth that outreach and education programs that engage public are required. Literature (discussed later in this section) and current market trends have amply pointed out how games bring out the best in people in terms of learning and productivity. Games have now transcended the bounds of virtual reality and entered our lives and the lives of others we know. Interactions in the gaming world translate into interactions in the real world. To play the game better, thus, needs collaborations in both worlds. This paper discusses the NASA and DARPA supported SPHERES Zero Robotics (ZR)[i] as a revolutionary program that achieves the goals of science, technology, engineering and math (STEM) education by calling upon students to play games with real satellites in space. ZR is an international, robotics programming competition where the robots are SPHERES satellites inside the International Space Station. Tournaments are ***free*** of charge and all that is required is a team of students, a

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mentor and access to a couple of computers with internet connectivity. Students program the robots to play the challenging games, ALL from a web browser. In the final competition, an astronaut runs the games on the satellites in microgravity and interacts with students live from the ISS (Figure 1). By leveraging the excitement of the virtual gaming world and providing the reality of astronauts, ISS satellite control and a final showdown event, ZR successfully inspires crowds of students, the way only NASA can.

Figure 1: Zero Robotics Middle School Finals 2010

<u>Space Education for All</u>

Since the 1980s NASA has played a very beneficial role in space education outreach in the United States, inspiring students and teachers across the nation. Two of NASA's largest educational programs: the NASA Explorer School (NES) and NASA Spaceward Bound programs are examples of outreach to promote student interest in science, technology, engineering, math, and geography (STEM-G) careers[ii].

The NASA "International Space Station Education Concept Development Report"[iii] states: *"Utilizing the International Space Station National Laboratory for education is an effort initiated in response to the 2005 NASA Authorization Act, which designated the U.S. segment of the ISS as a national laboratory".* The report shows a framework by which the goals are part of a pyramid: inspire a large number of students, engage a set of them, and educate a sub-set. A revolutionary education program would inspire a large number of students, allowing many to learn by directly ***engaging*** them. Since it began operations, the ISS has accommodated a number of education experiments. While multiple programs have reached a substantial number of students via demonstrations and videoconferences with astronauts, these events do not allow students to become ***engaged*** in actual research activities.

Bob Rogers, founder and Chairman of BRC Imagination Arts and winner of the NASA Public Service Medal, when developing NASA's master plan for the exploration of Mars as part of the Mars Exploration Program Analysis Group, presented five strategies of public engagement[iv]. The presentation, summarized by Mark Craig, makes three important points:

1. Effective and massive public engagement has important benefits beyond increased support. It enhances work force retention, morale and recruiting because "It's nice to be a part of something famous". It enhances "spin control" of unplanned events because it establishes a compelling context. The most profound benefit is that it builds a "psychological highway to space". If done well, public engagement builds the exploration and opening of the space frontier into the Nation's DNA.
2. Engagement is best achieved to the broadest audience through the use of a 'story'. As people are engaged by a story, goals in the story need only be important to the protagonists (us). Said in reverse, if people are not engaged by a story, explaining why our goals should be important to them will never be enough.

3. "Story" is an effective mechanism for dealing with potential showstoppers such as loss of interest after major accomplishments (Apollo 12 syndrome). It is also key in sharing the experience of space exploration because it takes people with us emotionally, beyond visually or tactilely

Important components in education are international collaboration in the fields of development of interest in space, providing easily accessible information and development of programs that will motivate the next generation workforce. Space Exploration educators across the globe are confronting challenges and embracing opportunities to educate and prepare students for an increasingly interconnected world. Collaboration is in the interest of the US as well. A recent National Research Council (NRC) Space Studies Board report[v] acknowledges that *''US problems requiring best efforts to understand and resolve are global in nature and must be addressed through mutual worldwide action''*. The report notes that educating *''a capable workforce for the 21st century is a key strategic objective for the US space program''*. It further recommends that the International Space Station (ISS) be utilized fully for education and research which also agrees with the Augustine Commission Report[vi].

Games – The Power of Virtuality

Games have proven to be good for people since as long as history has been documented because they allow us to build worlds that specifically tap into our evolutionary senses. Stuart Brown[vii] observed animal play in the wild, where he first conceived of *play as an evolved behavior* important for the well being and survival of animals, especially those of higher intelligence. Play, he concluded, has been known to pique human curiosity (exploration play), cause community collaboration (social filling play), charge better performances (adrenaline pumping play) and bring out the creative best in people (imaginative play). Jane McGonigal, from 42 Entertainment that produced the record-breaking *'I love Bees'* has researched the reasons for games bringing out the best in people[viii]. The positive outcomes of games, she suggests, are blissful productivity, urgent optimism and working in a collaborative environment and toward something agreed upon as an 'epic win'. Furthermore, the common theme among all the gaming blockbusters of today is the fact that they all break into reality[ix]: FarmVille lets Facebook users play with their real friends, Guitar Hero lets music loves play the game while playing music real-time on a real instrument, Nintendo Wii or the Microsoft Kinect use a real console to translate real actions into a video game. The internet, being the best platform for broadcast as well as conversation, has been the critical facilitator of games entering real lives of communities of people worldwide. The introduction of reality in games – picked up and virally spread by alternate reality games - has made the reasons to play them stronger and shown strong correlation between behavior in games to rational, economic behavior in real life[x]. Games are great tools to piqué human productivity and reward the brain[xi] because they provide easy-to-monitor bars of progress (eg. An evolving Avatar), multiple short and long term aims, an easy link of consequences to actions, elements of uncertainty to keep the user's interest, windows of enhanced attention as users race for a predefined goal and a crowd of players to play with or against.

II. SPHERES

The SPHERES program began in 1999 as part of an MIT Aero/Astro undergraduate class. Prototypes were built by the student class in 2000, flight satellites were delivered in 2003, and launched to the ISS in 2006. SPHERES became one of the first educational programs that launched student-designed hardware to the ISS. SPHERES consists of a set of tools and hardware developed for use aboard the ISS and in ground-based tests: three nano-satellites, a custom metrology system (based on ultrasound time-of-flight measurements), communications hardware, consumables (tanks and batteries), and an astronaut interface. They operate aboard the ISS under the supervision of a crew member (Figure 2).

Figure 2: SPHERES operates 3 satellites aboard the ISS (astronaut and MIT alum Gregory Chamitoff)

The ground-based setup consists of a set of hardware analogous to what is in Station: three nano-satellites, a metrology system with the same geometry as that on the ISS, a research oriented GUI, and replenishable consumables. The SPHERES satellites implement all the features of a standard thruster-based satellite bus. The satellites have fully functional propulsion, guidance, communications, and power sub-systems. These enable the satellites to maneuver in 6-DOF, communicate with each other and with the laptop control station, and identify their position with respect to each other and to the reference frame. The laptop control station (an ISS supplied standard laptop) is used to collect and store data and to upload new algorithms. SPHERES uploads new algorithms (ahead of time) and downloads data (after the session) using the ISS communications system.

Figure 2 shows a picture of a SPHERES satellite and identifies its main components. Physical properties of the satellites are listed in Table 1.

Diameter	0.22 m
Mass (w/tank & batteries)	4.3 kg
Max linear acceleration	0.17 m/s^2
Max angular acceleration	3.5 rad/s^2
Power consumption	13 W
Battery lifetime (replaceable)	2 hours

Table 1: SPHERES Physical Properties

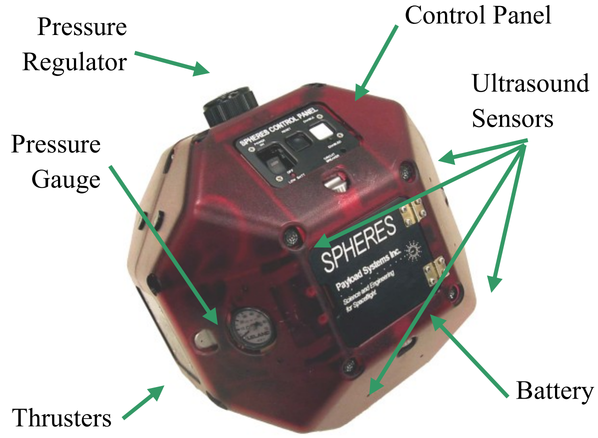


Figure 3: A SPHERES Satellite

SPHERES was designed to be a *facility* aboard the ISS, not just a single experiment, by following a set of design principles learned from previous MIT SSL experience[xii]. To provide the ability to involve multiple scientists in a simple manner, a SPHERES "Guest Scientist Program" (GSP) was created[xiii]. This program consists of a test development framework, a robust and flexible interface to the SPHERES flight software, a portable high-fidelity simulation, two laboratory test beds and data analysis utilities and supports the efforts of geographically distributed researchers in the development of algorithmsThe Zero-Robotics program expands the GSP with a simplified interface so that students at many different levels can program the satellites.

III. ZERO ROBOTICS HISTORY

Zero Robotics draws significant inspiration from FIRST robotics and shares common goals including building lifelong skills in science, technology, engineering, and math. A study[xiv] on the impact of FIRST Robotics shows that these competitions have an important effect on students and their involvement in STEM activities. FIRST Robotics concentrates heavily on the development of hardware, has a large registration fee and does not have any space-related components. Since SPHERES concentrates on the development of software, Zero-Robotics complements FIRST Robotics by providing students an avenue to develop innovative software, with the incentive that it will be tested by robots and astronauts in space at no cost to participants.

In fall 2009, the SSL conducted a pilot program of the Zero Robotics competition with two schools/10 students from northern Idaho. The competition was motivated by the idea of a satellite assistant robot[xv]. The first robotics competition aboard the ISS took place on December 9th, 2009. Zero Robotics was a component of NASA's Summer of Innovation, a nationwide program targeted at encouraging STEM education for middle school students. During this competition, 10 teams and over 150 students from schools in the Boston area worked for five weeks to program the SPHERES to compete in an obstacle course race. After diligently working, the students sent their programs to the ISS and watched the live competition on August 23rd, 2010. In fall 2010, Zero Robotics conducted a nationwide pilot tournament for high school students named the Zero Robotics SPHERES Challenge 2010. Over 200 students from 19 US states participated as part of 24 teams. The objective of the game was to complete the assembly of a solar power station by maneuver a satellite to dock with a floating solar panel then bring it back to the station to finish the mission, before the opponent does. The 2011-2012 ZR tournaments are led by MIT, TopCoder, and Aurora Flight Sciences under the sponsorship of DARPA and NASA.

IV. ZERO ROBOTICS TECHNICAL FRAMEWORK

ZR is comprises of a series of tournaments for middle school and high school students. Each tournament unveils a different game theme and has several competitions where students play the same or different games under the theme. Student teams submit an application on http://zerorobotics.mit.edu/. Upon acceptance, they can create, edit, share, save, simulate, submit code; all from the ZR website.

The general components of Zero Robotics are described below.

Game Design

For each tournament, the Zero Robotics development team designs a different game. The game meets the following criteria, developed from the lessons learned during previous instantiations of Zero Robotics tournaments and constraints of the SPHERES hardware and software.

- A game with relevance to state-of-the-art research with SPHERES, so that the work of students can contribute to future research at MIT, NASA, and other research centers.
- Each player controls one SPHERES satellite during the game which involves two players. Games of 3 players could be possible in the future since there are 3 SPHERES aboard the ISS.
- Each live ISS event is constrained by available ISS crew time to approximately 3 hours. For effective use of resources this translates to approximately 3-5 minutes per match between players and approximately 15 matches per ISS session.
- The game must be easily played in 2D for ground contests on the Flat Floor Facilities at MIT or other NASA centers, but expandable to use the 3D nature of the ISS for the finals; both the 2D and 3D versions of the game must work correctly in simulation.
- Since it is not possible to manifest game pieces to the ISS for each tournament, all game items apart from the SPHERES are virtual. Games must be designed such that playing them results in maneuvers and formation flight that are interesting to watch on the ISS.
- All matches must be bound within the physical playing area of an ISS lab
- Due to the dynamics of the satellites, games are slower than typical arena robotics games, and collisions are not allowed. Other approaches must be used to enhance the excitement of the competition.
- The game should be such that a large percentage of the participating teams are represented on the ISS. One method of implementing this is by requiring the finalist players to be submitted by alliances of multiple teams. This will enable teams to work

together for the finals aboard the ISS, increasing the number of teams that participate in the finals.

- Games should be challenging and compact at the same time so that the game code, player code and SPHERES satellite operating system code all fit in the highly constrained flash memory available on each satellite
- After the end of a match, each participating satellite communicates one 8 bit number to the laptop. Game scores should be such that they can be returned within these 8 bits so that scores of each ISS and ground match can be announced immediately after completion, rather than wait for all the test data to be downloaded from the ISS and analyzed.

Software Architecture

Typically, programming the SPHERES satellites requires users to have access to the Texas Instrument compilers for the SPHERES processor and familiarity with the Guest Scientist Program. None of these is possible for a tournament meant for high school students and below. Instead, MIT and TopCoder have developed a web-based interface to program the satellites which makes use of the same SPHERS high-fidelity simulation that is used to develop flight software.

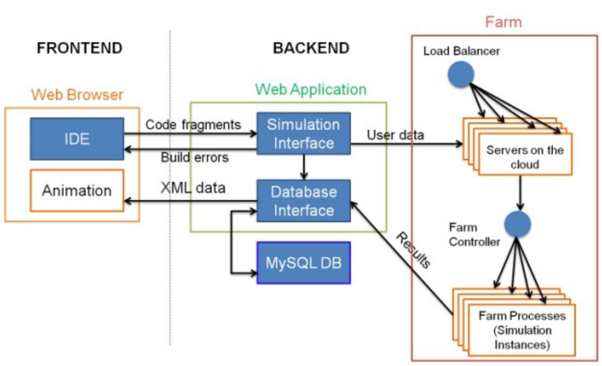


Figure 4: ZR Software Architecture

The programming takes place via a web-based GUI, which provides a simplified interface to the Guest Scientist API functions and enforces constraints that guarantee compatibility with the SPHERES compilers. Students have access to a text based editor as well as a graphical editor, for those with little or no prior programming experience. A distributed computation engine, hosted on Amazon EC2 virtual machines compiles the user code, links it with the core SPHERES software, and performs a full simulation of the program.. An Adobe Flash based front visualization, creates an animated representation of the results. The code programmed by the students via the web interface can be executed in the hardware.

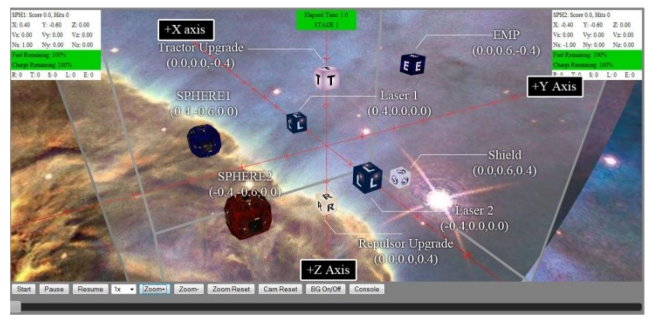


Figure 5: Example of a ZR Animation

Users write code inside the main function called *'ZRUser()'* available in each project and are not be allowed to change its signature. *ZRUser()* is called at every iteration of the satellite control cycle (once per second). User defined procedures are all called inside this main which has as its inputs, the position, velocity, attitude and attitude rates of each of the satellites and the time since the game begun. For running simulations, the code within and called by *ZRUser()* is inserted into a pre-defined template and called by the ZR simulation to control the SPHERES satellites.

Graphical Editor

The ZR graphical editor allows users with little or no C experience to write code using drag-and-drop programming. It is currently possible to see and generate C-code from the diagram view so that users can initiate their code with diagrams but can move on to more complicated code using the C editor. It uses the standard procedural language constructs such as if/then/else, calls, variable assignments, array iterators, range iterators, case-statements, etc. The Zero Robotics API procedures and functions as well as game specific

API functions are integrated into the drag-drop programming icons. Furthermore, user-defined procedures/functions and variables are supported.

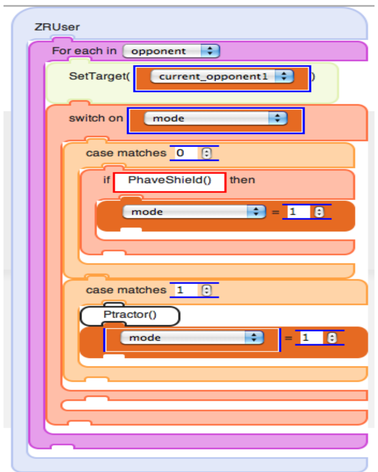


Figure 6: Example of code in the Graphical Editor

The graphical editor is written in JavaScript and is derived from the Waterbear JavaScript editor (http://waterbearlang.com). The implementation uses a Model-View-Controller paradigm where the block diagram and "C" views are different renderings of the same underlying model.

<u>Team and Project Management Tools</u>

Teams are organized into two types of members: team leads and team members. Users are required to create an account on the ZR website before submitting an application to a tournament. On acceptance, the user who submitted the application is designated as a team lead of his team - newly created team (unique ZR ID assigned) or a previously formed one. A team lead can then invite other users to join the team and assign more team leads. The ZR website provides users all the critical tools that they need to create, edit, share with others, compile, simulate and save all their projects and results. Figure 7, Figure 8 and Figure 9 below show the UI available to a user for doing the above actions.

The ZR simulation allows users to tweak different game parameters and choose simulation settings (Figure 10) so that they can test different parts of their code independently. They can simulate an individual project, race against another member of their team or race against standard players provided by MIT. The simulation also allows students to control the speed of the game to show the motion in real time, or up to 10 times faster. In a formal competition, these settings are fixed by MIT and the purpose of the simulation is to provide ample opportunities to test different versions of their strategies and finalize a robust submission.

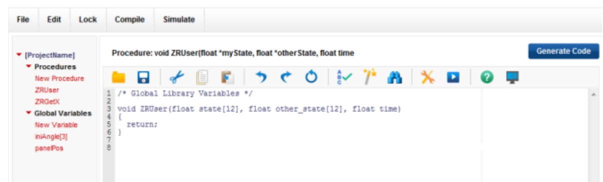


Figure 7: IDE Text Editor

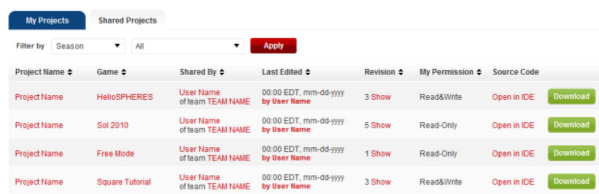


Figure 8: User Project Management tool

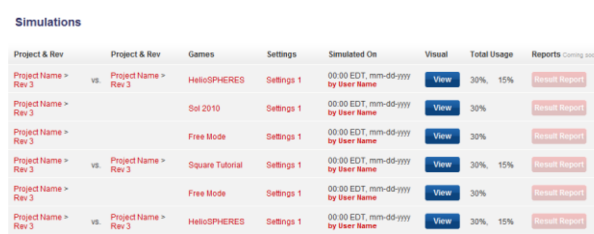


Figure 9: User Simulation Management tool

All through the tournaments, teams are given the opportunity to challenge other teams for informal scrimmages. The website provides the ability to select a user project and invite other teams to race their projects against the selected one – called a 'challenge'. Teams can accept or reject challenges using the provided UI and view the results, animations and leader boards for each challenge that they participated in (Figure 11). A simple interface is available to teams for submitting a project as an entry into a formal competition (Figure 12). MIT runs an automated competition using these submitted projects.

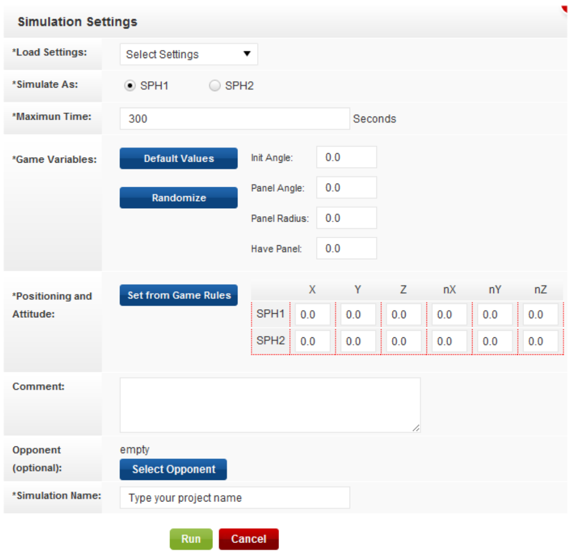


Figure 10: Simulation Settings

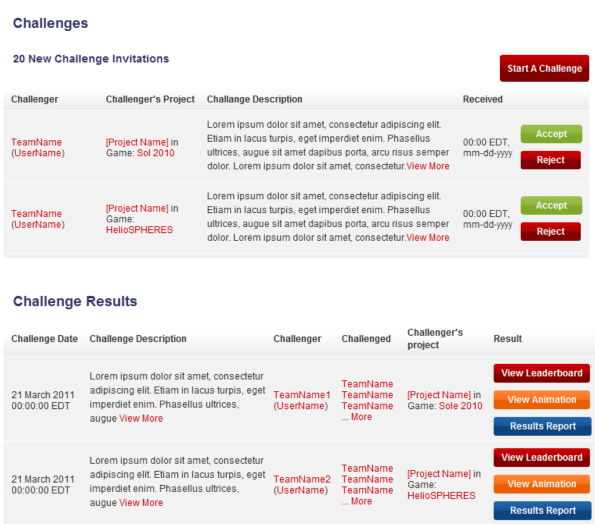


Figure 11: Tournament Challenges

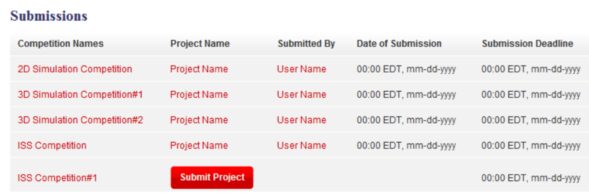


Figure 12: Submissions for Competitions

Tournament Structure

The 4 main phases in a ZR tournament are: 2D simulation phase, Flat Floor demonstration, 3D simulation phase and ISS final phase. In each phase, students program their players to play the competition's game. Each phase ends with the formal submission of each team's players, following which MIT runs an automated competition among all the submitted players and declares the results. The ranks and scores may be used for elimination immediately or stored for seeding for later phases.

Simulation Competitions

The Zero Robotics programming interface provides a simulation that interprets the program written by the students in the same way as it will be used in the hardware. In a simulation competition, MIT runs a complete round robin among all the submitted projects for that competition where every team competes against every other team, providing useful results for the students. However, the simulation does not replicate every aspect of the hardware; therefore the need for ground based testing. All results, reports and animations are made available on the website for users to review and improve their players

Ground Competitions/Demonstrations

Teams have the opportunity to run their software on the SPHERES ground hardware available on the Flat Floor facility at the MIT SSL. Plans for expanding this event to NASA Centers (initially Ames Research Center and the Jet Propulsion Laboratory) are underway. For flat floor operations, the satellites operate in 2D by floating on special air carriages that allow almost frictionless movement across the floor. The satellites can move autonomously using their thrusters, just like the ones aboard the ISS, and transmit data in real-time to the computers, which can display the motion of the satellites in the simulation environment, so that students can relate the hardware testing with their earlier simulation work. By watching the event webcast live, the teams have an opportunity to see the SPHERES satellites operating and learn differences between simulation and actual hardware.

Feedback from the 2010 participants strongly suggested that the importance of the ground competition scores be reduced in comparison to the simulation competitions because the facilities are not as well calibrated as the ISS. Extra mass, friction and the requirement of manual assistance to help the SPHERES move caused a lot of complaints. The 2011 ground event is a demonstration.

<u>ISS Competition</u>

Teams that reach the final round have their programs run on the SPHERES satellites aboard the ISS with the help of astronauts. The astronauts run the final robotics game on the ISS, act as referees and interact with participating students via a live video broadcast. The final competition is a big event at MIT where all teams are invited to attend, interact with each other and watch the video broadcast from the ISS. The event will be webcast live to all participants so that teams which could not attend the event at MIT can see it remotely. Such a strong and strategic culminating event acts as an incentive to motivate students and solidifies the impression of the program among amateur participants.

V. ZR 2011 – ASTEROSPHERES

The theme of the 2011 high school game is asteroid mining and it is based on the premise of NASA's future missions to explore near Earth objects. The game is called 'AsteroSPHERES' and the fictional story released as a mission statement to the participants is:

"Time is running out! Our planet's energy sources are dwindling and we have little time left to save the situation! BUT, not all hope is lost. Scientists have detected the presence of Helium-3 ore on two Near-Earth Asteroids, Opulens and Indigens. MIT engineers have built SPHERES satellites that can mine the Helium-3 and collect it in mining stations for Earth-transfer. The SPHERES satellites can extract the ore by spinning on (drilling) or revolving around (surface collection) the asteroids. More ore can be extracted if one satellite drills while the other collects from the surface of the same asteroid. The ore on Opulens is more enriched; however, it is protected by a layer of thick ice which has to be melted to mine it. Therefore, the mission to Opulens is much more difficult, but much more rewarding.

AsteroSPHERES

Figure 13: Game Logo

A large mining company has leased the SPHERES satellites and embarked upon a mission to maximize the collection and delivery of the Helium-3 ore from the asteroids before their orbits take them far from Earth. The satellites can collect tools that will help their mission, but if used maliciously, can disrupt the navigation of the other. Your mission, as a team of expert strategists to the company, is to devise and implement a plan to pick up the best items, extract the Helium-3 ore, deposit it at the mining station near the asteroids and signal your success back to Earth. You will be paired up with a variety of strategist teams. If you top the charts of total ore mined for the whole mission, you will emerge as the winning team and get a large percentage of the company's profits. While you do want to get ahead of the other teams and mine more ore, it is in your best interest to collaborate to *maximize ore collection. The energy future of mankind depends on you and fame and glory await you!"*

The 2011 game is focused on the topic of collaboration in competition and strives to answer the question of how teams can collaborate to achieve mission objections while also getting ahead to win the game? The results of the 2010 game, HelioSPHERES, showed a lot of aggressive play so much so that only 1 of the 10 finalist teams completed the game objectives on the ISS i.e. found the solar panel, picked it up and docked it to the station to complete assembly. All the other teams were concentrating on trying to break the opponent's game and prevent them from achieving the game objectives. The 2011 game strongly incentivizes communication and collaboration between the two players in the match such that playing 'together' gets each more points than playing attack/defense. Moreover, the competition score of each team is the sum of points accumulated by that team over all its matches in that competition. This will force teams to think beyond simply winning a match because they not only need to win and get bonus points; they also need to get a large number of points to hike up their aggregate. The 2011 tournament also requires that the 54 semi-finalists, chosen from all participating teams after the elimination rounds, form groups of 3 called 'alliances' and work together to make a common project for submission. The intension is to encourage teams to review the performances of their peers, form alliances with those they find complementary to their skill set and work collaboratively on the same player using our online tools.

Other lessons learned from ZR 2010 that we have followed up on in ZR 2011 include:

- Game rules being changed during the season: The game design for 2011 began in January 2011. The game has been iteratively tested by undergraduate students from an MIT class playing it. A subset of this game was played during the summer by middle school students in a formal but scaled-down ZR tournament
- Loss of interest from teams that fell back after the first elimination rounds: We have tackled this problem by allowing more teams (27 in 2011 as opposed to 10 in 2010) to reach the ISS finals as alliances.

Like the 2010 game, each player is constrained within finite resources of virtual fuel, virtual charge and code size. The virtual fuel allocation is a fixed percentage of the total SPHERES tank capacity so virtual fuel use is directly correlated to real satellite maneuvers. Similarly, the satellites have a finite amount of power to use the tools they collect which is *not* correlated to t..real battery power of the SPHERES.

<u>AsteroSPHERES details</u>

The game consists of three stages of 60 seconds each. Each player possesses a weak repulsor and a weak tractor which serves to repel and attract the other player, respectively. These can be used to either help or obstruct the progress of the other player, depending on the strategy chosen by each team.

Phase One: Tool collection.

Virtual tools are available to be picked up by the *players*: two lasers, a shield and a disruptor upgrade. A player can only pick one laser. To pick up the tools a satellite must pass through the tool's location at a velocity < 5 cm/s. The upgrade doubles the force of the tractor and repulsor... The shield protects the satellite from a repulsor or tractor of the opponent. The laser can be used to melt the ice on Opulens, attack the shield of the opponent and signal mission completion back to Earth. To use any of the items they must be pointed in the direction of the target. This phase does not earn points. The objective is to obtain the right tools for the strategy of Phase 2 and 3. Items that are not picked up in Phase 1 will disappear.

Phase Two: Asteroid Mining

Two asteroids, called Opulens and Indigens, will appear. To extract Helium-3, the players can either spin on (drilling) or revolve around the asteroids (surface collection), both of which earns points. If they collaborate on extraction operations on the same asteroid, such that one spins and one revolves, both SPHERES will earn more points.

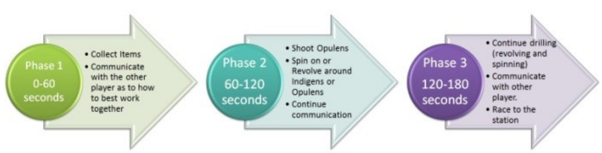
Opulens has more enriched ore (worth more points) but has a layer of ice that must be melted by shooting a laser at it before any extraction. Shooting the ice layer together earns points and melts it faster. SPHERES can begin mining Opulens as soon as the ice layer has melted. Indigens can be mined from the beginning of Phase 2, but will earn less points as it

Phase Three: Deposit mined Ore

At the start of Phase 3 sunlight melt Opulens' ice, so both asteroids can be mined through this phase. In the last 10 seconds of the phase, two mining stations will open. The first satellite to reach any station wilthe uniqueus points but if collision avoidance is activated during this phase, both players will be penalized and a substantial avoidance maneuver will likely disrupt their path. A match ends in four ways:

1. The first satellite to reach its station transmits its "done" command, which ends the match.
2. Both satellites reach their station (which earns points for *both* players).
3. Both satellites run out of fuel without reaching the station.
4. 60 second time cap reached in Phase 3.

The player with more points at the end of the match wins and earns bonus points.



Registration Status

ZR 2011 has received applications from 122 teams around the US of which 108 have been approved. Applications are open through Sept 16, 2011. Figure 14 shows the spread of participating schools in the US. Of the 24 teams that participated in 2010, 16 have returned to participate in 2011 and this includes all the 10 ISS finalists.

ZR is going international starting this year. A select group of 16 schools from Italy and Germany, handpicked under the supervision of the European Space Agency will play AsteroSPHERES on the same web platform as US schools. The ISS final competition will be conducted separately.

Figure 14: Map of registered US schools (not a complete set since registration is still open)

Phase	Dates	Deliverables
Reg'n	Sept 5 (Mon) Sept 10 (Sat)	ZR2011 application (from teams); *as announced* Kickoff event
2D Sim Comp	Sept 16 (Fri) Sept 11 (Sun) - Oct 5 (Wed) Oct 6 (Thu) - Oct 7 (Fri) Oct 13 (Thu)	Registration freeze; *hard deadline* 2D simulation competition MIT will run the autonomous sim. competition Ground Demo using 9 teams' code
3D Sim Comp #1	Oct 7 (Fri) - Oct 28 (Fri) Oct 29 (Fri) - Oct 31 (Mon)	3D simulation competition #1 MIT will run the autonomous sim. competition
3D Sim Comp #1	Nov 1 (Tues) - Nov 2 (Wed) Nov 3 (Thu) - Nov 4 (Fri) Nov 5 (Sat) - Nov 23 (Wed) Nov 24(Thu) - Nov 28(Mon)	Alliance preference submission Autonomous determination of alliances 3D simulation competition #2 MIT will run the autonomous sim. competition
ISS Finals	Dec 5 (Mon) Nov 29(Tue) - Dec 8 (Thu) Dec 20 (Tues)	ISS Strategy (from finalist alliances) Finalists to refine ISS Code ISS Finals on the International Space Station

Figure 15: Outline of dates in ZR 2011

VI. IMPACT ON EDUCATION

High level goals for outreach using ZR are to:

- *Engage students*, specifically from underserved and underrepresented communities, in STEM activities by giving them hands-on experience with the SPHERES hardware and software
- *Create educational materials for students* to be used both during the season and the school year for extended learning and sustained engagement

- *Increase educator capacity and comfort in teaching STEM subject matter* by working collaboratively with certified in-school and out-of-school educators from participating schools, school districts and/or community based organizations
- *Build critical engineering skills for students,* such as problem solving, design thought process, operations training, and team work. Ultimately we hope to inspire future scientists and engineers so that they will view working in space as "normal", and will grow up pushing the limits of engineering and space exploration.

MIT uses the unique CDIO Initiative for Engineering Education. CDIO stands for *"Conceive Design Implement Operate"* and offers an education stressing engineering fundamentals in order to create systems and products. By hands on engagement, it teaches students to appreciate the engineering process, contribute to the development of engineering products, and do so while working with an engineering organization. ZR follows the CDIO Initiative where students will *conceive* of a strategy to win the game, *design* a program using the SPHERES programming interface to demonstrate the brainstormed strategy, *implement* their codes and simulations using SPHERES hardware on the Flat Floor facilities and finally *operate* the SPHERES satellites through their programs aboard the ISS.

To evaluate if ZR had met its intended objectives and invite suggestions, surveys were sent to all the 2010 high school participants. The response was very positive. In ZR 2010, 20 of the 24 participating schools (83.33%) completed the survey. These 20 schools had a total of 182 students and 62 mentors. The average number of students per high school was 9.1 – the maximum student number was 20 and minimum was 3. The average number of mentors per team was ~ 3. Of the 182 participating students, 82.2% were male, 20.9% came from low income families, 3.1% had disabilities, and 12.15% of them had English as a second language.

In a September 2010 report, the President's Council of Advisors on Science and Technology released a report[xvi] that recommends that the federal government create opportunities for inspiration through individual and group experiences *outside* the classroom (recommendation #5) and notes that state and federal government can and should play a significant role in expanding opportunities for high-quality STEM-focused out-of-class activities. Recognizing the need of afterschool programs, we has partnered with the Massachusetts Afterschool Partnership (MAP) for all our middle school programs.

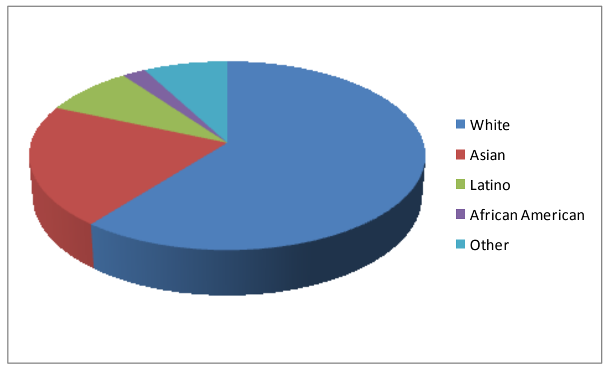


Figure 16: Ethnic distribution of ZR 2010 HS participants

From the feedback surveys conducted after the middle school program in 2010, the statistics show success in achievement of our goals. There were over 200 middle school participants from 10 schools across Massachusetts. 84% came from low-income families, 81% from ethnic minorities, 54% were female and 75% came from low-performing school districts. The youngest participant was a rising 4th grader! All ten programs had a retention rate of 88% or greater and a daily attendance rate of 90% or greater. Each of the 10 programs was exclusively supported by one MIT undergraduate mentor through the tournament. They ensured that the students individually and as a team made sufficient progress with programming the SPHERES and coding the strategy in order to complete the game successfully.

ZR2011 is going to be a season of international participation, inter-team alliance formation and collaboration, collaborative editing of projects, inter-player communication during matches, inter-player collaboration for formation flight in the ISS, inter-team scrimmages and more competitions than before. Feedback survey results will help us evaluate the success of each of these components and develop better games and competitions to improve the educational value of ZR.

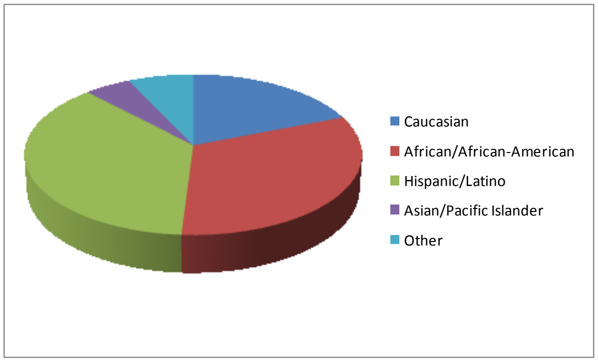


Figure 17: Ethnic distribution of ZR 2010 MS participants

VII. CONCLUSION

This paper has attempted to explain the usefulness of games in space education in the context of game design within the Zero Robotics program.

- Each ZR game has a fictional but feasible story to provide participants with an epic mission. The youth likes to save worlds and learn from heroes. A 'Star Wars' inspired droid (SPHERES) racing for revolutionary goals goes very far in inspiring them.
- The flash animation environment provides a sense of virtual worlds like a video game which allows programming to be fun and play than just writing code.
- ZR provides the opportunity of an epic win in a race that is literally out of this world. The incentive of ISS participation and astronaut interaction serves to motivate students all along. Also, since in the culminating event of ZR, all participants are invited to a common location to prepare for this 'epic win', the programming competition enters the real lives of people. Participants, who had been corresponding and collaborating, mostly over the internet can then meet each other and share the excitement.
- Games increase productivity by keeping up the sense of urgent optimism. ZR allows racing among team members and scrimmaging against other teams. These online tools as well as closely spaced competitions, i.e. multiple short and long term goals, keep the pace of performance high through the tournament.
- ZR games aim to incentivize collaboration among opponents, a valuable lesson for students because in real missions too, it is strategic collaboration that brings success rather than underhanded aggression. Students work together as a team, outside of their teams in alliances and together with opponents to achieve game objectives. Collaboration in so many layers is expected to lead to exchange of knowledge and communal discovery.
- ZR games are strategy and mathematics intensive which encourages analytical thinking and pique the problem solving interest of many. It provides food for different skill sets within a team.
- Every ZR game has random variables and participants are expected to write players that can deal with the element of uncertainty. While the online tools give users the ability to tweak these variables, their random nature makes for unexpected and interesting twists in the competitions.
- The program is free of cost and completely web-based. Requiring just mentor and student enthusiasm and minimal resources, very easily accessible and quickly scalable.
- Each competition and challenge returns a large set of results. Consistent feedback of performance allows teams to monitor their bars of progress. Participants have the opportunity to review performances of all others and form alliances that are stronger than any of its individual parts, leading to more evolved players.

The long-term objective of the ZERO-Robotics program is to engage high school, undergraduate, and graduate students, with age appropriate tasks. There are three long term phases envisioned for ZERO-Robotics:

1. *Phase 1*: a software design competition that allows students to have their algorithms run in the microgravity environment on SPHERES aboard the ISS. This phase began in 2009 and is currently in its 4th tournament.
2. *Phase 2:* a hardware design competition that enables students the opportunity to design enhancements that use or add to the SPHERES satellites to accomplish complex tasks not possible with the current hardware. By operating inside the ISS, with SPHERES, the design of this hardware requires substantial engineering skills but is low risk. This phase is expected to start in 2012.
3. *Phase 3* opens up the SPHERES program by creating an open solicitation for unique ideas on an ongoing basis. This phase is expected in 2014.

Each phase allows in-depth engagement, first software and then hardware, of crowds of students with real spaceflight hardware. Given the difference in the nature of each phase, game design of each phase will also be different in order to continuously achieve our educational goals.

ACKNOWLEDGEMENTS

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