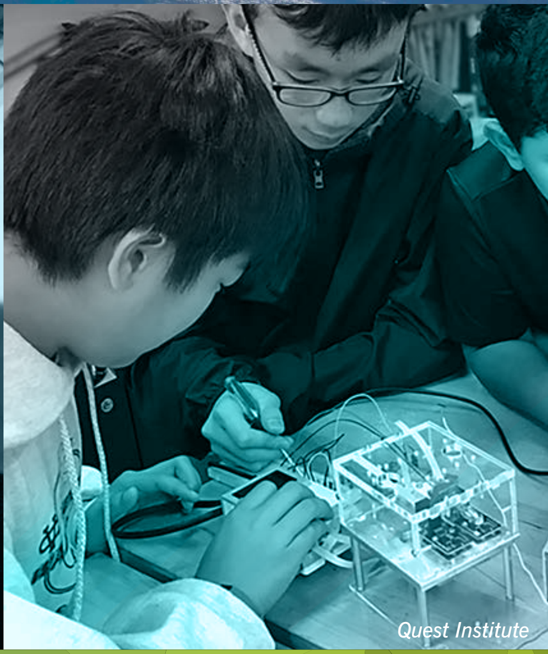
ISS NATIONAL LABORATORY

20 Years of Student Experiments
USING THE INTERNATIONAL SPACE STATION


NASA


SSEP


Dan Barstow


Quest Institute

ISS20 — 20 Years on the International Space Station

RELEASE DATE: NOVEMBER 10, 2020

SPACE STATION EXPLORERS

20 Years on the International Space Station

20 Years of Student Experiments Using the International Space Station

AUTHORS:

Daniel Barstow,
CASIS Senior Education Manager

Michael Roberts,
CASIS Vice President and Interim Chief Scientist

Diane Matthews,
CASIS Education Project Manager

Samantha Thorstensen,
CASIS Education Project Manager

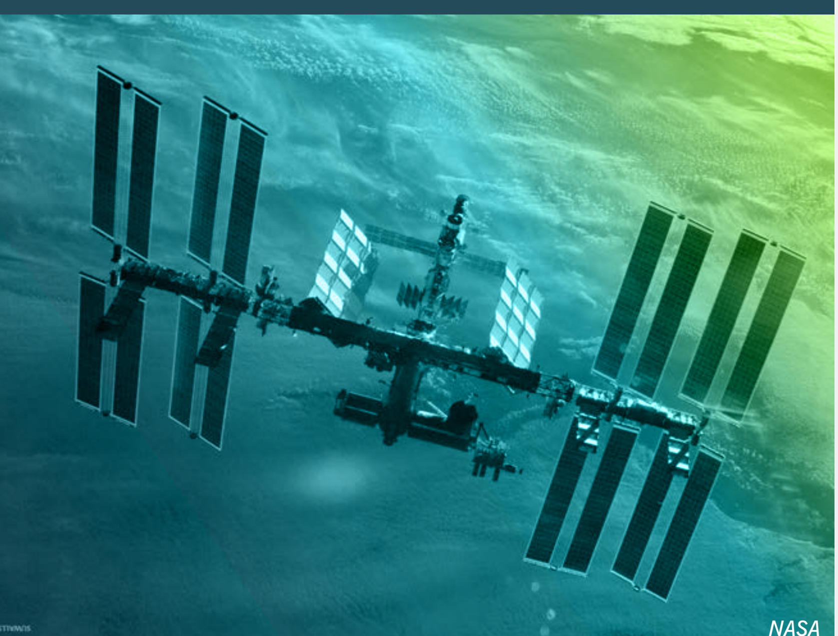
Cesil Alex,
Student Intern

EDITORS:

Jackie Rocheleau and Emily Tomlin

RELEASE DATE:

November 10, 2020



NASA

ISS NATIONAL LABORATORY
CENTER FOR THE ADVANCEMENT OF SCIENCE IN SPACE

About the International Space Station (ISS) U.S. National Laboratory:

In 2005, Congress designated the U.S. orbital segment of the ISS as the nation's newest national laboratory to optimize its use for improving the quality of life on Earth, promoting collaboration among diverse users, and advancing science, technology, engineering, and mathematics (STEM) education. This unique orbiting laboratory is available for use by non-NASA U.S. government agencies, academic institutions, and the private sector. The Center for the Advancement of Science in Space (CASIS) manages the ISS National Lab, under agreement with NASA, facilitating access to the permanent microgravity research environment, a powerful vantage point in low Earth orbit, and the extreme and varied conditions of space. To learn more about the ISS National Lab, visit www.ISSNationalLab.org.

SPACE STATION EXPLORERS

About Space Station Explorers:

Space Station Explorers is a community of educators, learners, and organizations that make STEM learning fun and exciting through connections with the ISS National Lab. We collaborate with many partner organizations on innovative programs and resources for K-12 students, educators, and the public, including opportunities to design experiments to launch to space!

Table of Contents

Executive Summary

> *"If you want to build a ship, don't drum up the [people] to gather wood, divide the work, and give orders. Instead, teach them to yearn for the vast and endless sea."*
> **—ANTOINE DE SAINT-EXUPÉRY**


NASA

The ISS has enabled a revolution in educational access to space.

The same assets that make the International Space Station (ISS) a powerful laboratory for scientists also make it an invaluable platform for student research investigations and educational outreach. Accessible through frequent launches, real-time connectivity to data streams from in-orbit experiments, and crew-member activities, the ISS offers access to a unique perspective of Earth, persistent microgravity to explore its effects on living and nonliving things, and the environmental extremes of low Earth orbit. Moreover, a global cadre of scientists, engineers, educators, and entrepreneurs are committed to pushing the envelope to convert innovative research and development (R&D) ideas into reality—including those that support science, technology, engineering, and mathematics (STEM) education.

The ISS enables students to think differently and explore thought-provoking questions about how plants grow on an orbiting platform, what aspects of climate change can be seen from the ISS, how gases and liquids behave differently in microgravity, and how radiation and temperature fluctuations affect the functions of solar panels. For the past 20 years, students have investigated these and other questions—designing, building, launching, and operating experiments on the ISS. They program and control robots, select targets for Earth photography and analyze space imagery, operate experiments in chemistry and physics, plant seeds exposed to the space environment, communicate via radio from ground to space and back, and even conduct cutting-edge genetic research.

This is a remarkable concept—that elementary, middle, and high school students have direct access to the ISS, using it as an extension of their classrooms. Now, on the 20th anniversary of sustained human occupation of the ISS, this report documents the scope and depth of the educational uses of the ISS. The report focuses specifically on actual student experiments (excluding activities in which students passively learn about the ISS or participate in lessons that present results of experiments done by others). The study team identified 17 programs that enabled such K-12 student experiments and collected detailed reports on the numbers of students, the types of experiments and learning experiences, and the depth of engagement. These programs are part of the Space Station Explorers consortium, managed by CASIS in support of the ISS National Lab. All numbers reported herein refer to U.S. K-12 student participants in these 17 programs.

Executive Summary

The results summarized below and detailed in the full report demonstrate that these programs have revolutionized and democratized educational access to space, engaging millions of students. What used to be the rare opportunity of a select few is now available on a large scale to virtually anyone who is interested. This education engagement is a poignant and tangible success story in the legacy of the ISS achievements.

GENES IN SPACE

SOME KEY FINDINGS INCLUDE THE FOLLOWING.

- The Space Station Explorers consortium includes programs offering a wide range of student experiment opportunities in multiple STEM domains.
- The programs align with and support U.S. national standards in STEM fields, with a special focus on inquiry-based learning.
- Over the past 20 years, 2.6 million U.S. K-12 students have participated in experiments using the ISS.
- Diversity and inclusion are a high priority for these programs, with 45% of participants identifying as a minority and 46% as female. Several programs focus specifically on under-resourced schools.
- Students work an average of 10 hours on program experiments, with many working over 100 hours over the course of the program.
- Students access the ISS via three primary pathways: launched experiments (8% of students), uplinked experiments (35%), and ground-truth experiments (57%).
- Almost 800 student experiments have been launched to the ISS.
- Programs have remarkable longevity, with six started more than a decade ago.

Although this study does not formally evaluate long-term educational or professional outcomes for students, the anecdotal and quantitative evidence is clear:

> *These programs have demonstrated the power to inspire learning and to motivate inclusion and diversity by enabling students to conduct authentic research using the ISS.*

Ultimately, this report offers data for policymakers and educators who can use this information to shape the future of educational programs in space. The educational utility of the ISS and other platforms in low Earth orbit is in the hands of government and business leaders as they consider the full extent of this work to date, determine its importance to the future of our nation, and create new opportunities for today's students and tomorrow's workforce.

Please note that this report was prepared by CASIS staff and may not represent the views of NASA.

Introduction

The ISS has enabled a revolution in educational access to space.

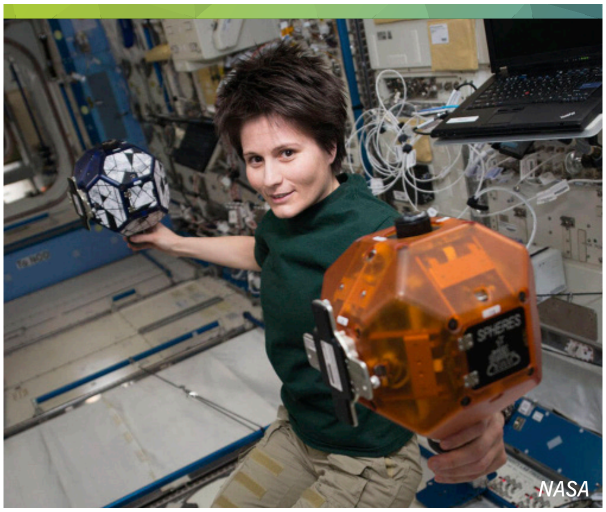
Over the past 20 years, 2.6 million U.S. students (K-12) have designed, launched, operated, or used data from experiments performed on the ISS. This immersive experience leveraging our natural curiosity about space is unprecedented in its depth, reach, and ability to inspire life-long learning. It is a major success story of the ISS.

This 20-year anniversary provides the perfect opportunity for a detailed review of these innovative programs, assessing numbers of students, depth of experience, and hours of engagement. This lays the foundation for looking forward, with recommendations for deepening the impact, expanding the reach, and exploring innovative ideas for the future.

Each of these programs (and dozens of others) engages students in authentic scientific research, inquiry-based learning, and practical applications of science, technology, engineering, and mathematics (STEM). The activities align with national educational standards, inspire students with the thrill of space exploration and discovery, and support workforce development in aerospace, technology, and other STEM fields. A diverse range of educators, scientists, and engineers developed the programs. All those involved sustain these programs with passion and creativity and by building partnerships focused on educational goals.

For example, students use the ISS to:

- program and control flying robots to do a set of tasks (via the program Zero Robotics),
- select targets for Earth photography and analyze space imagery (via EarthKAM),
- operate experiments in chemistry and physics to monitor heat flow (via Quest Lab),
- plant seeds exposed to the space environment (via Tomatosphere),
- conduct biomedical and genetics research (via Genes in Space), and
- design, launch, and analyze data from biology and chemistry experiments (via the Student Spaceflight Experiment Program, SSEP).



This report examines the 20-year history of educational engagement and outreach on the ISS, detailing the types of experiments, the nature of the student experiences, the array of the ISS resources available for educators and students, the impact on participants, and prospects for the future. The report is based on interviews and discussions with program leaders, educators, and participants, and a multi-year analysis of the diverse range of student experiments, numbers of participants, and depth of experience.

This report has 3 primary objectives. These are to:

1. provide a comprehensive view of these multifaceted educational programs,
2. offer insights into the power, depth, and reach of these experiences, and
3. lay the foundation for an informed discussion of innovative ideas and directions to sustain an educational mission leveraging space.

This report is intended for policymakers and educators who can use this information to shape the future of educational programs in space. The educational utility of the ISS and other platforms in low Earth orbit is in the hands of government and business leaders as they consider the full extent of this work to date, determine its importance to the future of our nation, and create new opportunities for today's students and tomorrow's workforce.

Introduction

ISS as a Venue for Student Experiments

The ISS is an amazing platform for student experiments. The same assets that make it an outstanding resource for scientists make it equally appealing and inspiring for students. It offers a global perspective to observe Earth, persistent microgravity to explore the effects of weightlessness, and the extremes of temperature, radiation, and near vacuum of space. It is accessible through frequent launches and real-time connectivity to data streams and astronauts who can operate experiments as needed. Perhaps most importantly, there is a global cadre of scientists, engineers, educators, and entrepreneurs who are thrilled and committed to push the envelope and convert exciting and contemporary ideas into reality.

The ISS enables students to think differently and ask thought-provoking questions such as:

- How do plants grow in microgravity?
- What aspects of climate change can one see from the ISS?
- On Earth, hot air rises—what happens in space?
- Can seeds survive extreme hot and cold temperatures?
- How do liquids, like oil and water, mix in microgravity?
- Do germs spread differently on a petri dish in space?
- Do solar panels work better in space or on the ground?

These questions can be explored in the unique environment of the ISS. They are some of the same questions asked by the ISS scientists, and all directly tie in with state and national standards. Weightlessness, extreme environments, Earth-observation capabilities, and engineering challenges all enable students to think about core STEM concepts in provocative new ways. The ISS is a powerful context for innovative learning.

The challenges for education developers and users of the ISS is to democratize access by making it affordable, feasible, scalable, and responsive to the needs of students and educators. Fortunately, education users can piggyback on solutions developed for business and research users of the ISS as well as create innovative solutions appropriate for students.

For example, Quest Institute for Quality Education has specialized in small size experiments (0.25 U, or 10 x 2.5 x 25 centimeters), with a standard data bus and mini widgets that students can incorporate in creative ways. Both the size and upmass are very low, keeping costs down. Magnitude.io sends an experimental lab to space and then distributes data from the experiment to participating students. The downlink costs are very low, and there are no limits on how many students can participate.

Other approaches are detailed in the report findings, illustrating how the education developers have found creative solutions to make the ISS truly accessible for education.

FIRST THE SEED FOUNDATION

The most important and lingering benefit of these programs is their inspirational value. It is a life-changing experience for a student to witness, in person or virtually, the launch of an experiment they designed and see it operational on the ISS. This is what NASA calls "inspiring the next generation." In numerous follow-up conversations with the participants, the message is overwhelming—these are powerful experiences for the students.

Beyond the inspirational value, each program has its own set of goals and domains of focus. However, all share a common vision of education centered on hands-on, inquiry-based learning. They all use the student experiments as a compelling context to engage the learner in a real-world problem. The programs give students the tools to understand the underlying STEM concepts, develop and operate the experiment, and analyze the results. This is scientific thinking brought to life.

The programs integrate different STEM fields. For example, a student experiment might focus on biology, use computers to access data, require careful design of the experiment, and involve data analysis skills for interpretation of the results. This integration across STEM is the hallmark of cross-disciplinary learning and emulates the real process of inquiry, exploration, and discovery.

The programs support state and national standards, and several of the programs provide explicit cross-referencing with STEM standards. For example, the U.S. Next Generation Science Standards call for inquiry-based learning and cite three aspects of science learning:

1. Disciplinary core ideas (grouped by life, physical, and Earth and space science)
2. Crosscutting concepts (such as cause and effect or systems and models)
3. Science and engineering practices (such as planning investigations or working with data)


NASA

The ISS STEM programs combine these three aspects of science standards with the specific learning goals based on the domains and details of the experiments. Similarly, the programs implement standards-based approaches to technology, engineering, and math.

Percent of programs that serve each grade level group:

41%	100%	29%
ELEMENTARY SCHOOL	MIDDLE SCHOOL	HIGH SCHOOL

Percent of programs that cover each STEM domain:

100%	82%	71%
MATH	TECHNOLOGY	ENGINEERING
65%	47%	24%
LIFE SCIENCES	PHYSICAL SCIENCES	EARTH AND SPACE SCIENCES

Introduction

Scope of this Study

This study focuses on one key aspect of the ISS education: actual student experiments that use the ISS.

It does *not* include activities that simply inform students about the ISS, the broad reach of astronaut tweets and other social media, or classroom activities that might be hands-on and inquiry-based but do not directly involve experiments using the ISS. While those outreach activities have real value, we focus here on the revolutionary shift from outreach to direct participation in the ISS experiments.

THIS STUDY FOCUSES ON K-12 STUDENTS ENROLLED IN U.S. SCHOOLS. This includes both formal and informal venues, such as schools, at-home learning, after-school and summer programs, museums, and independent learners—all based in the U.S. In short, within this age group: anybody, anytime, anywhere. It does not include older students in universities, colleges, community colleges, or other post-high school programs. While the ISS and its education programs are, of course, international, this study was established with the goal of looking at the reach and impact on U.S. students. Thus, the data reports from each U.S.-based partner specifies both the full global reach and the numbers of U.S. students.

THIS STUDY COVERS 20 YEARS OF THE ISS EDUCATION. This year the ISS reaches a major milestone—20 years of continuous human occupation since the November 2, 2000 arrival of the Expedition 1 crew. This report contains data from the year 2000 through the end of 2019 (the last available year with full data at the time of this analysis). Program operators have maintained detailed records over this time frame. For example, Amateur Radio on the ISS (ARISS), in which students use ham radio to talk directly with the ISS astronauts, was one of the first operational experiments on the ISS. Students had their first contact with astronauts on November 13, 2000, just 11 days after the first crew arrived. ARISS is still going strong after over 1,000 such contacts. Most program data are actual values, and some are calculated as reasonable estimates or extrapolated from trends. The lead contact for each program reviewed and confirmed his or her program data prior to publication of this report.

THIS STUDY HIGHLIGHTS THE ISS NATIONAL LAB. This report was prepared by CASIS, manager of the ISS National Lab, in collaboration with its partner educational programs. Most of the cited experiments take place in the U.S. orbital segment of the ISS. However, the ISS is an integrated spacecraft, and some experiments may take place in non-U.S. modules of the ISS or be supported by non-U.S. crew. This report includes all student experiment programs sponsored, supported, or partnered with the CASIS and the ISS National Lab. It does not, however, include data from programs run and primarily used by other nations.

APOLOGIES TO ANY MISSED PROGRAMS. Within the above scope, the authors worked diligently to be comprehensive. However, given the large scale of the ISS and its 20-year history, it is likely that some very worthy programs are not included. For example, commercial operators and research scientists might include K-12 students in their experiments in ways that are not reported. In other experiments, investigators might want to keep some of their research data confidential. The authors apologize for any such oversight and welcome any information to add to future reports.

ARISS

Introduction

Programs with Flight Experiments

This study looked at the following 17 programs that develop and operate student experiments. Each is described in detail in the Appendix.

AMATEUR RADIO ON THE ISS (ARISS)	direct ham radio communications with the ISS to talk with astronauts
ANTS IN SPACE	compare ants adapting to space with ground experiment
EARTHKAM	select targets for Earth photography
EXOLAB	operate experiments in the ISS lab and compare to ground experiments
GENES IN SPACE	design and launch genetics experiments
GROW LAB	test plants in a ground-kit for possible use in the ISS experiment
HIGHER ORBITS	hands-on workshops leading to flight experiments
HIGH SCHOOL STUDENTS UNITED WITH NASA TO CREATE HARDWARE (HUNCH)	wide variety of technical projects for use on the ISS
NATIONAL DESIGN CHALLENGE (NDC)	competition for custom-built launch experiments
ORION'S QUEST	support scientists for their in-orbit experiments
QUEST LAB 1+2	remote-control in-orbit experiments and ground kit
QUEST LAB 3	custom-built experiments launched to the ISS
SPACE STATION ACADEMY	online training as if astronaut candidate, using Earth observations
STUDENT SPACEFLIGHT EXPERIMENTS PROGRAM (SSEP)	community-based program to design and launch experiments
TOMATOSPHERE	plant and monitor seeds returned from space
WISCONSIN SPACE CRYSTAL	explore optimal chemistry for in-orbit crystal growth
ZERO ROBOTICS	develop code to control a robot on the ISS

All these programs are members of the **Space Station Explorers** consortium. Established in 2016 as the centerpiece of the ISS National Lab's education program, the consortium provides a venue for collaboration among the programs and a way to help educators, students, and other users see a unified package instead of disconnected pieces.

The full consortium currently has 44 member organizations. All are directly involved in developing or supporting the ISS education activities. Members include nonprofits, STEM organizations, under-resourced school districts, museums, after-school programs, and businesses. Members meet annually at an ISS Education Summit, collaborate on projects, promote cross-fertilization, and build outreach and visibility. A website provides articles, updates, and links to programs and learning activities. All these efforts work for the successful growth, operation, and impact of the ISS education.

NASA

Three major initiatives illustrate the collaborative nature of the consortium:

SPACE STATION AMBASSADORS – Educators, scientists, and other interested experts reach out to broader audiences to highlight educational opportunities, train educators, and support implementation. This program has grown well beyond initial expectations, currently with 1,195 registered and active ambassadors.

SCHOOL SPACE LAB – Just as schools have labs for biology, physics, and chemistry, School Space Lab offers schools a coordinated set of the ISS education materials and activities for a school space lab. Schools select which activities and resources support their local priorities. All included resources and activities feature the ISS education, especially opportunities for student experiments using the ISS.

LEARN AT HOME – During this COVID-impacted era, learning at home has become a major challenge for schools, parents, and students as they navigate online resources. Space Station Explorers launched the ISS Learn at Home initiative to provide free online activities, including most of the student experiment programs, in this new context. For example, in 2020 Genes in Space ran their normal competition with students working at home. They received 556 entries from over 1,000 students, about the same level as during a normal year (559 submitted in 2019).

All CASIS-affiliated programs provide quarterly metrics on the numbers of students reached, summarized in CASIS's quarterly reports released to NASA and publicly posted. However, these data include the full gamut of services—not just experiments directly involving students, but all outreach and student learning activities.

COLLECTING 20 YEARS OF DATA – Therefore, this study required a focused examination and collection of new data, *showing only those students directly involved in experiments*. The study also required a full retrospective, with data going back the full 20 years of the ISS. Fortunately, almost all the programs have been methodical about collecting data on numbers of participants, both for their internal value in monitoring the work of the programs and for their external value to convey impact.

For this study, each program provided year-by-year data on numbers of participants and the nature of the study activities. This extensive data collection included a methodical review to clarify the data, resolve any discrepancies, and otherwise ensure integrity and cross-program consistency for this report.

The authors of this study thank the programs for their hard work, diligence, commitment to accuracy, and willingness to share these data. The result is an unprecedented look at a 20-year history of this revolution in educational access to space in support of large-scale student experiments.

Educational researchers who want to use the full data sets for further study can contact the authors of this report.

DAN BARSTOW

Findings & Insights

Total Participants

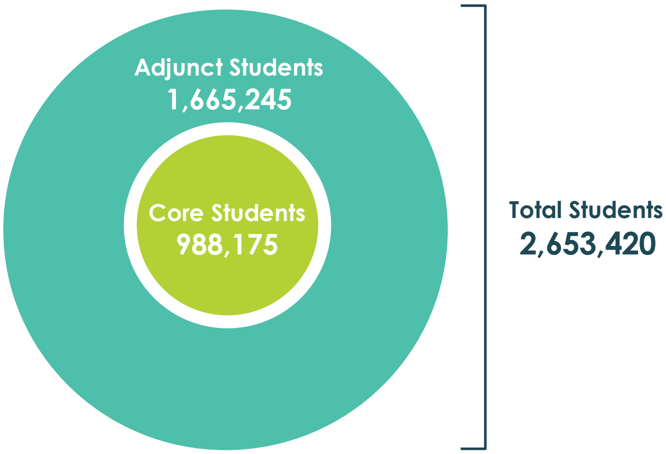


FIGURE 1: CORE + ADJUNCT = TOTAL STUDENTS

	CORE	ADJUNCT	TOTAL
ARISS	6,600	220,000	226,600
ANTS IN SPACE	15,713	0	15,713
EARTHKAM	668,159	0	668,159
EXOLAB	35,311	0	35,311
GENES IN SPACE	8	6,728	6,736
GROW LAB	18,050	0	18,050
HIGHER ORBITS	37	1,113	1,150
HUNCH	18,591	0	18,591
NDC	275	0	275
ORION'S QUEST	41,852	0	41,852
QUEST LAB 1+2	3,355	13,420	16,775
QUEST LAB 3	1,464	0	1,464
SPACE STN ACAD	1,171	0	1,171
SSEP	1,064	172,288	173,352
TOMATOSPHERE	169,663	1,244,195	1,413,858
WI SPACE CRYSTAL	9	1,091	1,100
ZERO ROBOTICS	6,853	6,410	13,263
	988,175	**1,665,245**	**2,653,420**

Program developers noted an important distinction in two levels of student participation in student experiments. The most intensively involved students ("core") worked directly on the experiments. However, in many programs a larger group of students ("adjunct") provided support, prepared detailed proposals in a competition, or participated in some but not all aspects of an experiment. Both groups have real involvement in the experiment.

As one example, Genes in Space runs an annual competition for students to do genetic research on the ISS. Of the several hundred applicants, only one team is selected to execute the experiment. However, the applicants, especially the 10 finalist teams, put in extensive work and design real experiments for the ISS. As another example, Zero Robotics runs a competition to write software that controls the motion of a soccer-ball sized robot on the ISS. Many students learn coding, write programs, and run simulation tests. However, only about half eventually uplink and run the experiments on the ISS.

Therefore, this report presents data based on two levels of participation:

CORE STUDENTS – those who built, launched, or operated the experiments

ADJUNCT STUDENTS – everyone else who participated, proposed, or supported experiments

Note that neither group includes students who simply participated in outreach activities or did classroom activities that did not directly involve an ISS-based experiment. That number is much larger (5,680,014 in 2019), but outside the scope of this report.

A few key findings from the data:

a. **This is a remarkably complete data set.** All programs have provided comprehensive data since the programs began, in some cases covering the full 20 years. Educational studies rarely have access to such full, long-term data.

b. **These programs have exceptionally large reach.** 2,653,420 students participated, of whom 988,175 (core students) explicitly designed, launched, or operated the experiments.

c. **Two programs have worked with over 100,000 core students.** Sally Ride EarthKAM tops the chart, with an impressive 668,159 students who selected targets for Earth photography. Tomatosphere provided tomato seeds from the ISS to 169,663 students, who planted them, monitored their growth, and submitted data to the program scientists.

d. **Competition-based programs reach well beyond the few winners.** Genes in Space had eight students who won the competition and launched their genetics experiments yet had 6,736 who did substantive work in classroom experiments and flight proposals.

Findings & Insights

Reaching Diverse Students

Diversity and inclusion are a high priority for these programs, with special efforts to include ethnically diverse, low socioeconomic, and female students. This has essential value both for the individuals served and for the richness of ideas that emerge from diverse populations in schools, communities, and the workforce.

This is especially important because having students do experiments on the ISS might initially sound like something exclusively for honors and A-level students. In fact, these programs are designed for the full range of students. Often the students with the least experience and confidence in STEM may be the most responsive to these exciting opportunities—experiencing hands-on science quite differently from the typical textbook learning.

CASIS has featured diversity in its mission, action plans, and the grants awarded to support larger-scale engagement with under-represented populations.

CASIS grants for diversity included:

- SSEP was used solely and specifically to enable low socioeconomic student participation.
- For the SciGirls program, Twin Cities PBS created videos that featured high school girls who had developed and launched experiments to the ISS.
- Orion's Quest connected inner-city students in Detroit with the ISS scientists to help perform ground-truth experiments.

Quest Lab has done ambitious work to assure that their ISS experiments are accessible to and used by under-represented populations. When they launched their Quest 2 Lab (an electronics kit for heat flow experiments in the classroom and on the ISS), they did all their field testing in a special program for students who had struggled in school, including having flunked at least two science courses. These students responded remarkably well to this opportunity and succeeded in both classroom and in-orbit components of the experiment. One of the students was selected as "the ISS Student of the Year" for recognition at the annual ISS Research and Development conference.

As another example, CASIS partnered with the Florida Boys & Girls Club program on a major $1.5 million proposal to the National Science Foundation for a workforce development program. The grant, if awarded, will use the ISS student experiment opportunities to inspire and engage low socioeconomic middle school students, connect them with role models in local aerospace businesses, and help the students plan pathways of study for future aerospace careers.

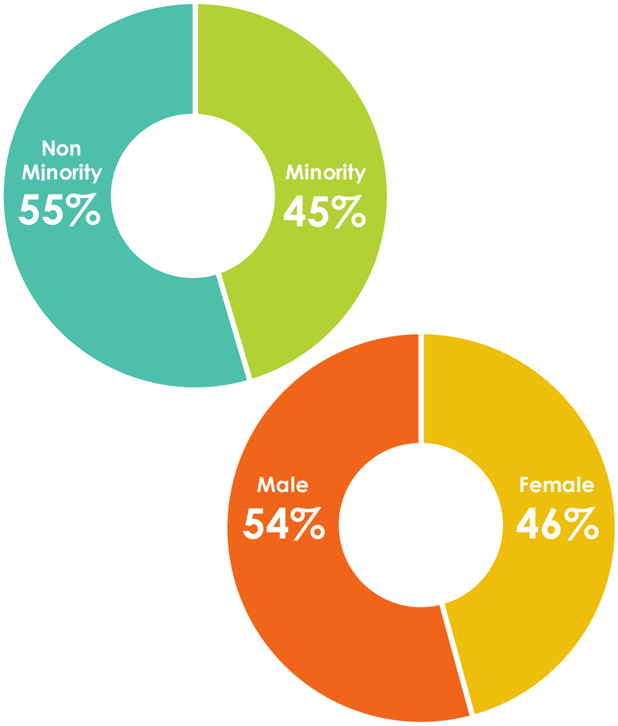


FIGURE 2: STUDENT ETHNICITY AND GENDER (2019)

This figure shows the percentage of students who identify with an underrepresented ethnic group or identify as female, based on available data from 2019. (About two-thirds of the programs report ethnicity and gender.) All programs highlight ethnic and gender diversity in their materials and make special efforts to reach ethnically diverse, low socioeconomic, and female students. For more details, see this report's Reaching Diverse Students section. Some key insights:

a. **The overall average ethnic participation is above the national average.** 45% of program students are from underrepresented ethnic groups versus 31% of U.S. elementary and secondary students.

b. **All programs cite a goal of ethnic diversity, and each has noteworthy success.** The proportion of participants from underrepresented ethnic groups ranges from 33% to 78% for these programs.

c. **Females are nearly equitably represented.** 46% of program students are female, versus 51% of U.S. elementary and secondary students who are female.

Findings & Insights

Hours of Engagement

This study uses *hours each student worked on the experiment* as the measure of depth of experience. This is a practical standard, enabling a realistic comparison across projects. While a more detailed analysis of project activities might provide a more sophisticated evaluation, that is beyond the scope of this study. Program leads agreed that hours of engagement provided a viable and accurate approach to compare across programs.

Figure 2 presents the average and total hours students worked on the experiments. Note that "everyone" (core + adjunct) worked a base number of hours—then for some programs core students worked additional time. The data are capped at 200 hours, though hundreds of students have done well beyond that.

A few key findings:

a. **All students average over 40 hours per experiment.** Across programs, all participants average 47 hours overall, with core students spending an average of 78 hours per experiment.

b. **Six programs engage core students over 100 hours per student.** Clearly, students are highly engaged. These six programs all involve preparing and launching a student experiment. This is not simply doing a school assignment—these students worked many hours both during and outside of school to make sure their experiment was flight-ready and successful.

c. **Total engagement is over 27 million student-hours.** This shows the impressive reach, depth, and appeal of the ISS student experiment programs.

	Avg Hour Per Student			Total Student Hours	
	EVERY-ONE	CORE ADDS	CORE TOTAL	EVERYONE	CORE ONLY
ARISS	15		15	3,399,000	99,000
ANTS IN SPACE	10		10	157,133	157,133
EARTHKAM	15		15	10,022,383	10,022,383
EXOLAB	4		4	141,244	141,244
GENES IN SPACE	14	149	163	92,743	1,304
GROW LAB	10		10	180,500	180,500
HIGHER ORBITS	101	23	124	115,888	888
HUNCH	65		65	1,208,415	1,208,415
NDC	195	5	200	53,500	53,500
ORION'S QUEST	4		4	167,408	167,408
QUEST LAB 1+2	3	11	14	47,445	47,445
QUEST LAB 3	200		200	292,800	292,800
SPACE STN ACAD	43		43	50,640	50,640
SSEP	38	126	164	6,556,877	174,496
TOMATOSPHERE	3	2	5	3,783,737	454,048
WI SPACE CRYSTAL	10	190	200	12,710	1,800
ZERO ROBOTICS	83	3	86	1,077,025	564,225
	47		**78**	**27,359,448**	**13,617,229**

FIGURE 3: HOURS STUDENTS WORKED ON EXPERIMENTS

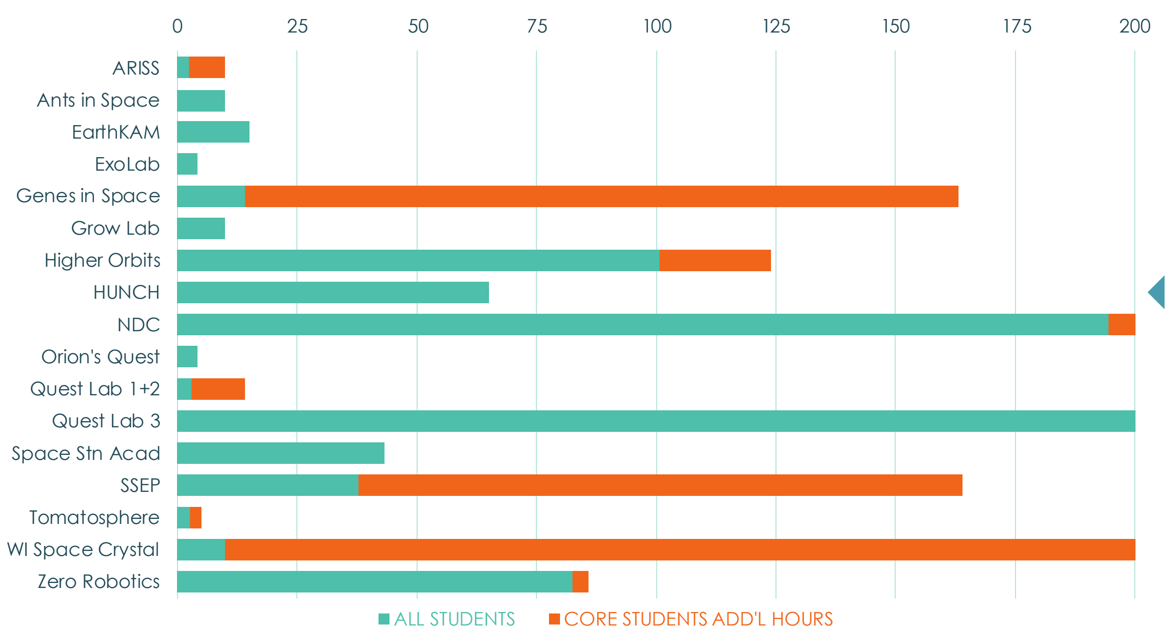


FIGURE 4: GRAPH OF HOURS STUDENTS WORKED ON EXPERIMENTS

Findings & Insights

Comparing Programs

This two-axis grid captures how each program achieves the dual goals of student reach (number of participants) and depth (hours of engagement). In general, it is desirable for educational programs to expand both reach and impact, which would be reflected in programs migrating to the upper right quadrant of the grid (many students, many hours). Individual programs balance these goals based on program structure, funding, and other factors.

Key insights from this analysis:

a. **All programs have found creative ways to expand reach and deepen impact.** No programs are in the lower left quadrant of "low reach" and "low depth."

b. **Programs serving many students have well-defined materials readily deployed.** For example, every couple of years, Tomatosphere has a new batch of 1.2 million tomato seeds, with online curriculum ready for classroom use. EarthKAM uses an online registration and training system. SSEP uses a community-wide implementation model, poised to deploy when a district signs up.

c. **Programs requiring extensive support by educators focus on fewer students.** For example, Higher Orbits runs a week-long academy for students to conceive and design experiments. Quest Lab 3 does a summer academy to train educators to use the technical tools for their experiments.

d. **Over time, most programs invent better ways to expand reach and depth.** For example, Quest Lab figured out how to have students operate an in-orbit experiment, uploading commands and downloading data, thus reaching many more students at much lower cost than if each group of students had to build and launch their own experiment.

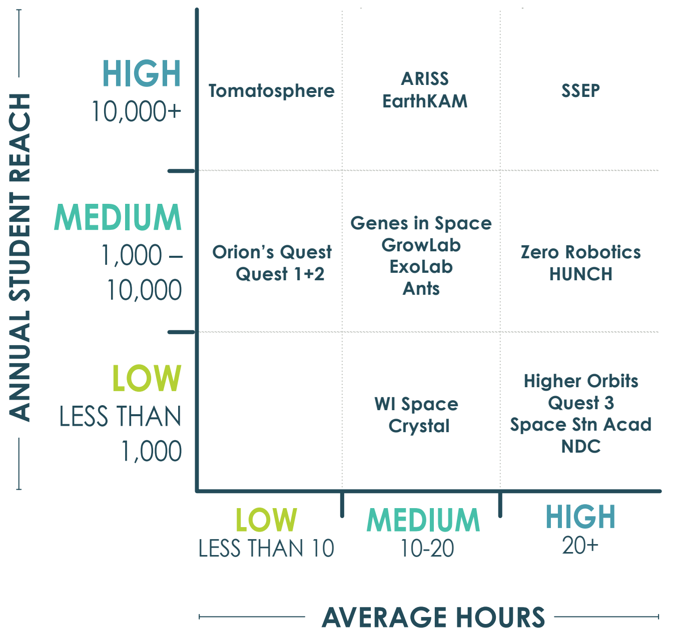


FIGURE 5: TWO-AXIS GRID OF PROGRAM IMPACT; UPPER RIGHT IS "MANY STUDENTS, MANY HOURS."

HIGHER ORBITS

Findings & Insights

Annual Growth Over 20 Years

These figures show annual growth for each program and overall. The numbers are all U.S. student participants. A few key insights:

a. **The programs have grown dramatically over 20 years.** In 2000, ARISS launched the first student experiment program, reaching 515 students. The next year, EarthKAM and Tomatosphere were added. This growth of programs and students continued over the following years.

b. **They currently engage over 300,000 students annually.** In 2019 (the most recent full year), 15 programs reached a total of 326,989 students.

c. **Almost all the programs are still operating.** Of the 17 programs studied, all but 1 (NDC, designed as a limited-duration test project) are still active and used by students. All the rest, due to motivated leadership and popularity with users, continue well beyond their early years of development and experimentation.

	TOTAL	ARISS	ANTS	EARTHKAM	EXOLAB	GIS	GROW LAB	HIGH ORB	HUNCH	NDC	ORION'S	QUEST 1 + 2	QUEST 3	SSA	SSEP	TOMATO	WI CRYSTAL	ZERO ROBOT
2000	515	515																
2001	37,831	18,540		2,166												17,125		
2002	38,677	9,270		4,823												24,584		
2003	53,590	7,210		14,293					43		0					32,044		
2004	59,819	6,695		15,906					103		602					36,513		
2005	74,193	13,905		27,071					130		1,224					31,863		
2006	81,338	11,845		20,693					363		2,156					46,281		
2007	89,543	18,025		10,526					484		1,458					59,050		
2008	94,073	13,905		8,514					472		1,494					69,688		
2009	100,996	11,330		20,661					617		1,430					66,938		20
2010	106,006	6,695		18,267					852		1,939					77,813		440
2011	135,821	10,815		31,445					1,061		1,939		12		4,980	84,219		1,350
2012	140,206	16,480		18,016					1,149		2,100		84		12,344	89,063		970
2013	236,536	10,815		114,444					1,265		2,030		144		9,492	96,963		1,383
2014	246,485	10,300	7,051	95,751					1,605	55	2,240		180		16,020	111,563		1,720
2015	211,356	9,270	8,145	80,701					1,679	90	2,310		384	112	11,040	96,175		1,450
2016	209,970	15,450	517	49,617		707		125	1,786	65	3,080		192	370	21,144	115,386		1,530
2017	213,757	14,420		57,622	3,615	905	3,600	250	2,053	55	5,040	2,275	120	345	38,685	82,862		1,910
2018	195,720	14,420		50,904	19,990	2,289	5,550	425	2,354	10	5,390	3,245	192	174	22,398	66,069	600	1,710
2019	326,989	6,695		26,739	11,706	2,835	8,900	350	2,575		7,420	11,255	156	170	37,249	209,659	500	780
TOTAL	**2,653,420**	**226,600**	**15,713**	**668,159**	**35,311**	**6,736**	**18,050**	**1,150**	**18,591**	**275**	**41,852**	**16,775**	**1,464**	**1,171**	**173,352**	**1,413,858**	**1,100**	**13,263**

FIGURE 6: NUMBER OF PARTICIPANTS IN EACH PROGRAM, EACH YEAR

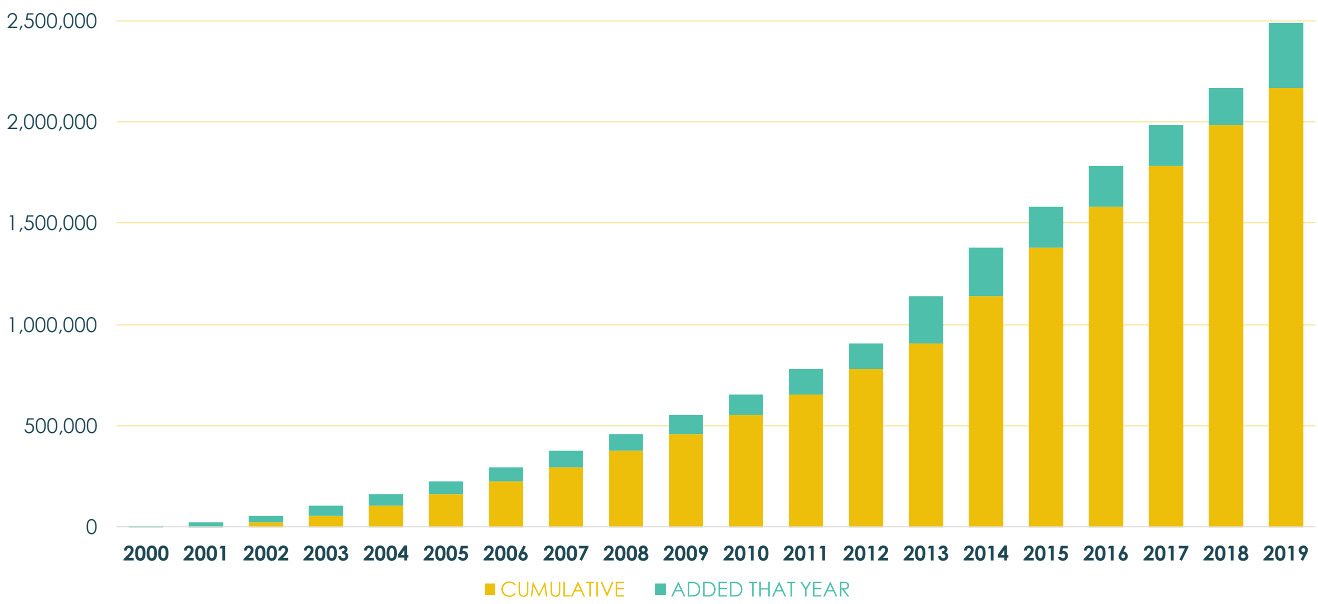
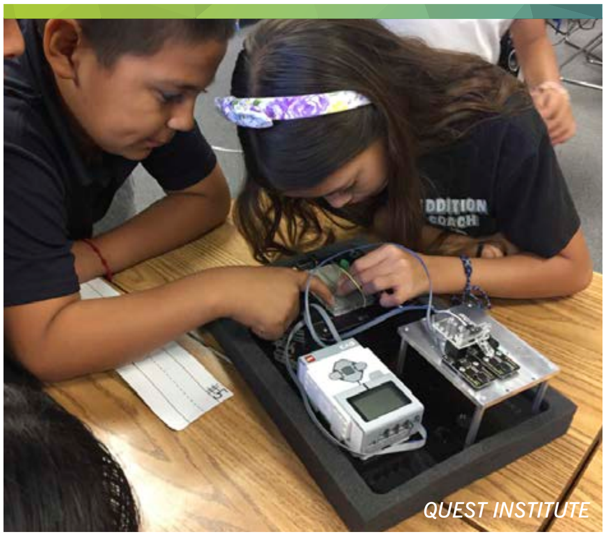


FIGURE 7: CUMULATIVE TOTAL PARTICIPANTS OVER 20 YEARS

Broadly speaking, programs use three separate ways to access the ISS: launching physical experiments, using remote control or other digital communications, and using classroom-based experiments to compare with the ISS experiments.



	LAUNCH	REMOTE CONTROL	GROUND KIT
ARISS		226,600	
ANTS IN SPACE			15,713
EARTHKAM		668,159	
EXOLAB			35,311
GENES IN SPACE	6,736		
GROW LAB			18,050
HIGHER ORBITS	1,150		
HUNCH	18,591		
NDC	275		
ORION'S QUEST			41,852
QUEST LAB 1+2		16,775	
QUEST LAB 3	1,464		
SPACE STN ACAD		1,171	
SSEP	173,352		
TOMATOSPHERE			1,413,858
WI SPACE CRYSTAL	1,100		
ZERO ROBOTICS		13,263	
TOTALS	**202,668**	**925,968**	**1,524,784**

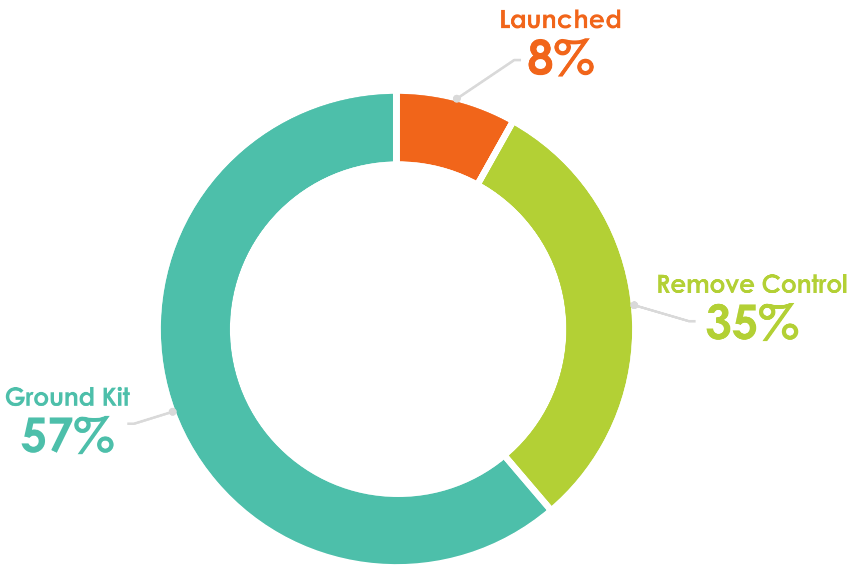
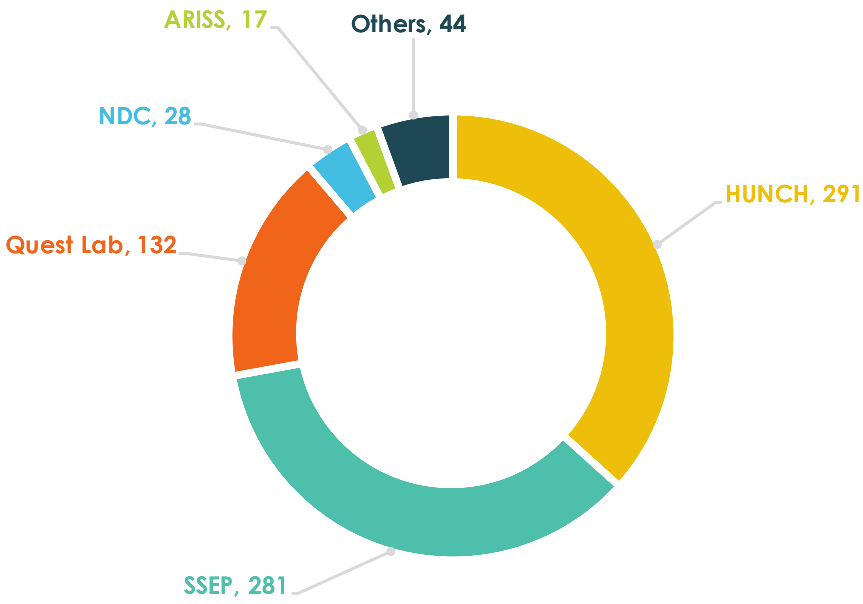


FIGURE 8: PERCENTAGE OF STUDENTS WHO USE THE THREE DIFFERENT WAYS TO ACCESS THE ISS

Findings & Insights

Experiments Launched

In terms of experiments launched, these charts show number of experiments sent by each program.



	EXPERIMENTS LAUNCHED
ARISS	17
ANTS IN SPACE	1
EARTHKAM	0
EXOLAB	6
GENES IN SPACE	6
GROW LAB	0
HIGHER ORBITS	8
HUNCH	291
NDC	28
ORION'S QUEST	0
QUEST LAB 1+2	9
QUEST LAB 3	132
SPACE STN ACAD	0
SSEP	281
TOMATOSPHERE	10
WI SPACE CRYSTAL	4
ZERO ROBOTICS	0
TOTAL	**793**

FIGURE 9: NUMBER OF EXPERIMENTS LAUNCHED BY EACH PROGRAM

Some key insights:

a. **Twelve programs have launched 793 individual experiments**. This is an impressive number. Each experiment represents a daunting amount of work by a group of students passionately committed to their own space experiment.

b. **Digital communications provide low-cost direct access to the ISS.** Four programs (ARISS, EarthKAM, Quest Lab, Zero Robotics) use direct communications, such as uplinking code, downlinking data, or using voice communications to operate experiments.

c. **Ground-based experiments have the largest reach.** Tomatosphere, for example, enables students to plant tomato seeds that have been on the ISS.

d. **Many students are involved in launching or operating experiments.** Although programs like Genes in Space that have an annual winning team get a lot of visibility, the reality is that over 200,000 students have been directly involved in launched experiments, and over 700,000 in remote-controlled experiments.

Special Topics

Earth Observation

Earth observations from the ISS have provided inspiration and education to students, teachers, and the public over the last 20 years. It is not possible to count the number of education users of Earth imagery; but Earth observation from the ISS, for both enjoyment and science, is likely the single largest educational reach of the ISS—and hence warrants special mention in this report.

The Earth Science and Remote Sensing (ESRS) and Crew Earth Observation (CEO) teams at NASA's Johnson Space Center work with crew who take imagery from the ISS and curate the entire astronaut photography database. The teams share the knowledge and relevance of Earth observations with millions of people around the world every year, through Earth Observation newsletters, articles, webinars, and the widely used Earth Observatory Image of the Day. They also curate the Gateway to Astronaut Photography to make the full archive of images freely available.

Astronauts can take hundreds of photos of Earth on a daily basis. Many say it is one of their favorite activities to take compelling images as they look out the Cupola and other Earth-facing windows. While astronauts can take photos for their enjoyment, many also take photos requested by scientists, educators, and students. Astronauts can photograph time-sensitive and dynamic events such as hurricanes, volcanoes, aurora, cities at night, cloud patterns, varying landscapes, glaciers, deforestation, and seasonal changes. The photos are beautiful, revealing, and dramatic.

These images have both scientific and educational value. Scientists routinely select and uplink several photography targets of Earth per day based on the ISS orbital paths and visible events. These images are used as a complement to satellite images for diverse studies of Earth's dynamics. The ISS offers:

- astronauts using human judgement to select and compose photos in real time,
- low Earth orbit as a powerful vantage point,
- a wide range of lenses for high detail (2-3 meter pixels) and broad context views,
- variable angles of sun illumination to highlight surface topography,
- night photography that captures stunning resolution to cities and human presence,
- aurora photography unavailable from any other source, and
- an archive of over 50 years of imagery that enables change-over-time analysis.

These photos, now numbering over 3.5 million from the ISS, are all free and in the public domain. Students can review, select, and analyze photos, to learn about Earth system science, human geography, orbital dynamics, agriculture patterns, climate change, and so much more. As just one example, students review photos of glaciers over multiple years to monitor their retreat as a metric of global warming; astronauts are asked to take new photos of major glaciers each year. The photos also have powerful inspirational value, for students and the public, as they see our ever-changing planet from space.

Sally Ride EarthKAM, one of the featured programs in this report, goes one step further, enabling middle school students to select their own targets for a computer-controlled camera on the ISS. Since 2001, over 600,000 U.S. students have selected targets. Each student averages 15 hours of engagement in this program, including learning about Earth observation, monitoring the ISS orbital path, selecting targets, reviewing the downloaded photos, and doing other related activities in curriculum support materials.

A few other statistics confirm the large-scale reach and appeal of Earth photography from the ISS:

a. **Astronauts' tweeted images** from the ISS are extremely popular. Scott Kelly tweeted over 1,000 Earth photos to his more than 5 million followers. @Space_Station has 3.8 million followers and includes several Earth photos every week. These are widely liked and re-tweeted.

b. **Astronauts have published dozens of books** with Earth images. "View from Above" (National Geographic) culls from the 319,000 Earth photos taken by Terry Virts.

c. **NASA's Gateway to Astronaut Photography of Earth** (NASA's central repository) had more than 23 million photo downloads in 2019, including 660,999 by U.S. education users.

d. **Windows On Earth** (a website highlighting Earth photos) had 971,436 image views in 2019.

e. **HDEV** (live video of Earth from the ISS) averaged 81,000 unique viewers per day, with a total of 318 million views over its five-year history.

f. **The ISS Above** (a plug-in device for TVs, typically for use in schools) reaches 263,340 students.

g. **Apple** sponsored dramatic Earth videos from the ISS, for use as screen savers on Apple TV. Apple does not publish the number of viewers of these Earth videos, but more than 50 million people have Apple TV units.

Clearly, Earth observation from the ISS is exceptionally popular with students and the public. It is a powerful educational activity for inquiry-based learning about Earth and a way to inspire respect for and appreciation of home planet Earth.

Special Topics

Amateur Radio

Amateur Radio on the ISS (ARISS) warrants special attention for several reasons. It was the first operational STEM outreach experiment of any kind on the ISS. It has engaged students over the full 20-year history of the ISS, with over 1,300 international contact events. It has embodied the spirit of experimentation with a series of bold innovations. The whole endeavor has been driven by volunteers—ham radio operators who push the technical envelope to support education for the sheer thrill of exploration and discovery.

Via technical and legal tests, amateur radio operators (hams) become licensed to use specific radio frequencies for experimental and hobby telecommunications. Over 750,000 U.S. citizens are hams. In fact, 125 of the more than 200 ISS astronauts obtained their license prior to flight—an essential requirement for them to use the in-orbit ham radio. Astronauts participate, voluntarily, during their personal time on the ISS as an invigorating way to stay connected with young people and support education.

On the ISS, the ham radio setup uses either of two onboard radios, seven external antenna systems, and a multi-voltage power supply—all passing the ISS flight certification reviews. In 2020, new equipment, with a 25-watt, VHF/UHF transceiver, was installed to enhance the communications capabilities. Virtually all work to build, launch, operate, upgrade, and sustain this system is done by volunteer hams (thank you!).

As we celebrate this 20th anniversary of sustained human presence on the ISS, we need to give credit to ARISS as the first operational STEM outreach experiment on the ISS. November 13, 2000, just eleven days after the crew of Expedition One arrived, ARISS successfully conducted its first radio contact experiment. This was an auspicious beginning to the ISS as a tool for wide-spread use. Volunteers did the first experiment to bring to life the educational value of the ISS. Before the internet phone was introduced on the ISS, the astronauts frequently employed the ham radio to talk to family and friends via the ARISS ground station volunteers. The ARISS radios also provide an official backup communications system for the ISS crew to contact the ground if the primary systems are out of service.

Each interested district submits a proposal for a limited set of opportunities, with selection based on the school's commitment to use the event as a spark for other related learning activities about radio, communications, and the ISS. Students prepare questions for the astronauts and coordinate their communications setup with a local (or remotely accessed) ham. Then, during a roughly 10-minute fly-over, students use the radio system to talk directly with an in-orbit astronaut (ham-licensed) to ask questions and get answers. It is a powerful experience for the students and involves educational technical work before and after this experiment. Since November 2000, students in the U.S. have participated in over 450 ARISS contacts, and internationally, over 1 million students have participated in ARISS contacts.

Yet this is just part of the ARISS activities. When the radio is not used for voice communications, it is switched to either voice or digital repeater mode. The digital repeater mode, similar to text messaging or twitter, employs coded messages from the ground that are sent to the ISS radio, that in turn re-transmits them. This enables the ground station to extend its geographical reach—and provides a thrilling experience communicating with other hams via the ISS. During 2017, 1,873 hams used this system to send 88,783 messages—an average of 243 messages per day. The messages are brief, but all connect directly through the ISS.

ARISS's creative team and ham colleagues have deployed several other communication experiments and developed the ability to download images and live video streams from the ISS, all using their own ham radio communication systems, with no need for support from NASA or mission control. Tens of thousands of images are downloaded each year by students and ham radio operators. In one creative experiment, a radio was embedded in an obsolete spacesuit that was purposely jettisoned from the ISS. Once deployed, the lifeless spacesuit looked eerily reminiscent of a lost space crew member from a science fiction movie. Hams communicated with this "SuitSat" as an experiment in weak-signal space communications. The ARISS-space agency safety collaboration required to enable the ISS crew to hand-deploy SuitSat from the ISS opened doors for others to safely deploy satellites off the ISS, sparking a new commercial industry initiative. Looking to the future, hams are building on the ISS experiences to design radio systems for use on future Moon bases in collaboration with NASA's Artemis initiative.

Truly, these hams embody the inspiring spirit of life-long learning and exploring, and demonstrate that the ISS is not a destination, but a tool for us all to inspire and engage.

Program Operations

ISS Resource Utilization

The ISS is one of the most complex engineering achievements of all time. It took decades to plan, assemble, and prepare for human occupancy—and we are now nearing the 20th anniversary of continuous human presence onboard the orbiting laboratory. The ISS is an international partnership, with complex technological challenges, operations support from several control centers around the world, multiple resupply launches per year, and over 200 astronauts who have built and operated the ISS. Over one hundred experiments are currently in operation, supported by dozens of companies specializing in in-orbit operations. This is a major endeavor.

The education programs described in this report are an inherent part of this grand mission. Standing on the shoulders of giants, these educational activities take full advantage of all that has taken place to make the ISS real. In fact, education is one of the defined priorities for the ISS, essential for the contribution to global STEM education and for inspiring the next generation aerospace workforce. In its directive to CASIS, NASA unequivocally states that STEM education is one of the core lines of work.

What is the incremental cost for these educational applications? What ISS resources are required? And how do these resources compare with other uses of the ISS?

The answer is that these educational programs are incredibly effective in their use of a surprisingly low amount of the ISS resources.

NCESSE

As one example, SSEP has launched 266 student experiments. Each experiment is a low-mass (40 gram) 8-inch flexible tube with compartments (a mini-lab) creatively used by students for experiments in biology, chemistry, and materials science, to test how fluids mix in microgravity. To further limit upmass and downmass, 10 experiments are packaged together in a box only 10 x 10 x 20 centimeters (2U). Then in-orbit, astronauts require a minimal amount of time to access the experiments. They unclip the compartments, shake the tube as needed, and put it back in the case—typically 30 seconds, capped at two minutes per experiment on a crew interaction day.

Key findings:

a. **Limited mass for launch and return** – Most of these projects use low-upmass experiments or existing in-orbit resources. Six of the experiments involve downmass. A bag of 1.2 million tomato seeds has three kilograms of mass—when returned, those seeds reach 200,000 students. The most significant upmass relates to ARISS, which has launched a series of radio equipment over its 20-year history.

b. **Limited use of astronaut time** – Most of these projects require no or very modest amounts of astronaut time. Implementing Genes in Space and Zero Robotics experiments takes the most significant amount of astronaut time. ARISS uses astronaut time for the school contacts—however, per agreement with NASA and the astronauts, this is volunteer time by the astronauts.

c. **Several projects use data from existing research projects** – For example, Ants in Space, Orion's Quest, and GrowLab all operate ground-based experiments to compare with on-orbit data provided by partnering scientists.

d. **Digital communications reduce upmass and downmass** – An increasing number of projects use digital communications to operate experiments and downlink data. For example, Quest Labs operates a thermal dynamics experiment, which requires students to upload a program and download data. This can be repeated dozens of times a day, with no need for new upmass or astronaut time.

Compared to the full array of scientific research and business experiments on the ISS, education uses an exceedingly small fraction of the ISS resources.

Program Operations

Cost to Participate

These programs are remarkably cost-effective. They have all found ways to keep their in-orbit operational costs low, their educational curriculum readily distributed, their classroom materials inexpensive, and their training costs low. Many of these programs are free for students, with the costs underwritten by generous support from sponsors or the organization's own operating budget.

Programs launching student experiments involve real expenses for equipment, testing, launch, in-orbit operations, and ground support. CASIS and the programs have worked collaboratively to keep these actual costs as low as possible. NASA provides CASIS with an annual allocation for upmass, downmass, data communications, and in-orbit astronaut time. CASIS in turn allocates a portion (typically about 5-10%) of these assets to the education programs. Also, the program partners have found creative ways to keep costs down, such as reducing experiment size and launching experiments in batches.

The following programs are free for student participants:

ARISS

EARTHKAM

ANTS IN SPACE

GENES IN SPACE

HUNCH

ORION'S QUEST

TOMATOSPHERE

WI SPACE CRYSTAL

ZERO ROBOTICS

The following programs use data uplinks and downlinks to keep costs under $500 per class:

EXOLAB

GROWLAB

QUEST LAB 1+2

SPACE STATION ACADEMY

The following programs launch student experiments, charging $5,000 to $25,000 per experiment:

HIGHER ORBITS

QUEST LAB 3

SSEP

NASA

Program Operations

Grants Awarded by CASIS

As part of its allocation from NASA, CASIS awards grants to educational programs, based on competitive applications and a formal review process. The selection criteria prioritize innovative approaches that maximize use of the ISS, support solid student learning, and make special efforts to reach under-represented populations.

CASIS has awarded 47 grants, averaging $80,181 and totaling $3,768,501. These grants enabled recipients to develop new experiments, launch and operate them in-orbit, and deploy them with diverse populations. Several of the awards promoted collaborations among multiple partners.

Examples of awards include:

- **SSEP** – support for low socioeconomic districts
- **ARISS** – operational support for school contacts program
- **TERC** – development support for Windows on Earth in-orbit experiment and website
- **Quest Institute** – innovative development of programs for under-represented students
- **Orion's Quest** – development support for citizen science curriculum
- **SciGirls** – video series highlighting female students who launched experiments to the ISS

The number of education awards peaked with 12 education grants in 2017, but resource constraints have limited the ability of CASIS to sustain funding at prior levels. Emphasis is now placed on education awards for resource allocation that leverage third-party funding not provided by CASIS.

CASIS has also pursued external funding to support these programs. Most notably, CASIS submitted two proposals to the National Science Foundation, in active review: Launching Space Careers ($1.5 million) and Student Mission Control ($300,000).

Several programs have received generous financial support from external sponsors. Some notable examples:

- **Boeing** – Genes in Space
- **Marvel** – Guardians of the Galaxy Experiment Design Challenge
- **Monsanto** – Tomatosphere
- **New England Biolabs** – Genes in Space
- **Northrup Grumman** – Zero Robotics
- **Raytheon** – School Space Lab
- **Teledyne Brown** – EarthKAM

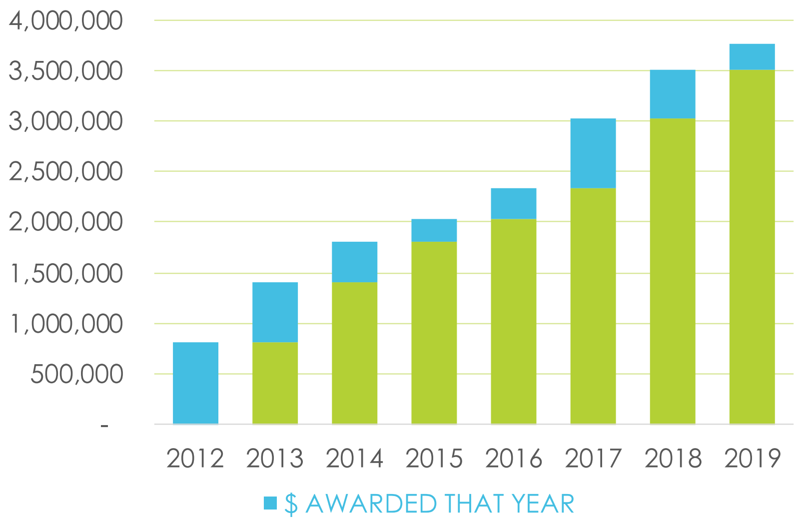


FIGURE 10: CUMULATIVE GRANTS AWARDED BY CASIS FOR EDUCATION PROJECTS

Program Operations

ISS Education as a Business Incubator

Along with being a powerful platform for research, technology development, and educational initiatives, the ISS also serves as a business incubator, helping mature in-space business models and facilitating growth of the market economy in low Earth orbit. While this is particularly apparent for the aerospace sector and in the biomedical and technology industries, education has emerged as an additional business opportunity domain.

Demand for service providers in the educator sector is on the rise globally as the need for improved workforce development becomes paramount. Furthermore, the 2020 transition to remote learning platforms as an emergency response has fueled a new movement to reimagine best practices for engaging students and to reflect on how best to train our youth for success in life and in their future careers. Institutions in this sector include private, public, and nonprofit groups, but also for-profit businesses.

As a rough estimate, education and the ISS involve a few million dollars of annual budgets, which cover program operational costs, contracted flight support, participation costs by local districts, and other related expenses. (This excludes the cost of the ISS and its ongoing operational support.)

One example illustrates the nature of such business. SSEP, operated by nonprofit National Center for Earth and Space Science Education (NCESSE), immerses hundreds of students in a formal research proposal competition at the local level. In each district, 50-100 teams design and propose microgravity experiments, with one selected from each district for launch and operation on the ISS. NCESSE provides a comprehensive educational package and contracts with Nanoracks for the launch and in-orbit operations. A district pays $25,000, typically through a combination of district funds and local philanthropy. If a community does not have the funding, NCESSE will find funders to get the community aboard. CASIS has provided funding support for under-resourced districts. In 2019, SSEP launched 41 experiments for a net budget of $1,025,000. SSEP has multiple repeat customers and has sustained its operations since 2011.

In this example, CASIS funding was about 10% of the total. Hence CASIS grants help launch and expand the reach of innovative programs, but the bulk of the funding comes from other sources, such as national and local philanthropy, industry support, and district participation fees, making these businesses sustainable.

This model and strategic approach of leveraging public-private partnerships, as well as external funding, has allowed CASIS and the ISS National Lab to expand its STEM portfolio and increase student engagement while maintaining a steady level of grant expenditures.

The following businesses (for-profit and nonprofit) were launched specifically for the ISS and student experiment programs:

- **ARISS**
- **Genes in Space**
- **Higher Orbits**
- **Magnitude.io**
- **NCESSE**
- **Orion's Quest**
- **Quest Institute**

The following existing businesses added these new lines of work based on the value of the ISS as an educational tool:

- **EarthKAM (U.S. Space & Rocket Center)**
- **Grow Lab (Fairchild Tropical Botanic Garden)**
- **Space Station Academy (Virtual High School)**
- **Tomatosphere (First the Seed Foundation)**
- **Zero Robotics (MIT)**

Finally, several for-profit companies provide essential technical and operational support for these and other initiatives, deriving revenue from educational programs (albeit typically at discount rates):

- **Alpha Space**
- **Nanoracks**
- **ProXopS**
- **Space Tango**

Education is a unique market, combining altruistic goals and financial realities. These companies have maintained their focus on education involving the ISS, while keeping their underlying finances viable and in some cases profitable. They also have demonstrated a refreshing openness to collaborating with other participants in this market sector as they all mature their business models and develop innovative ways to use the ISS for education.

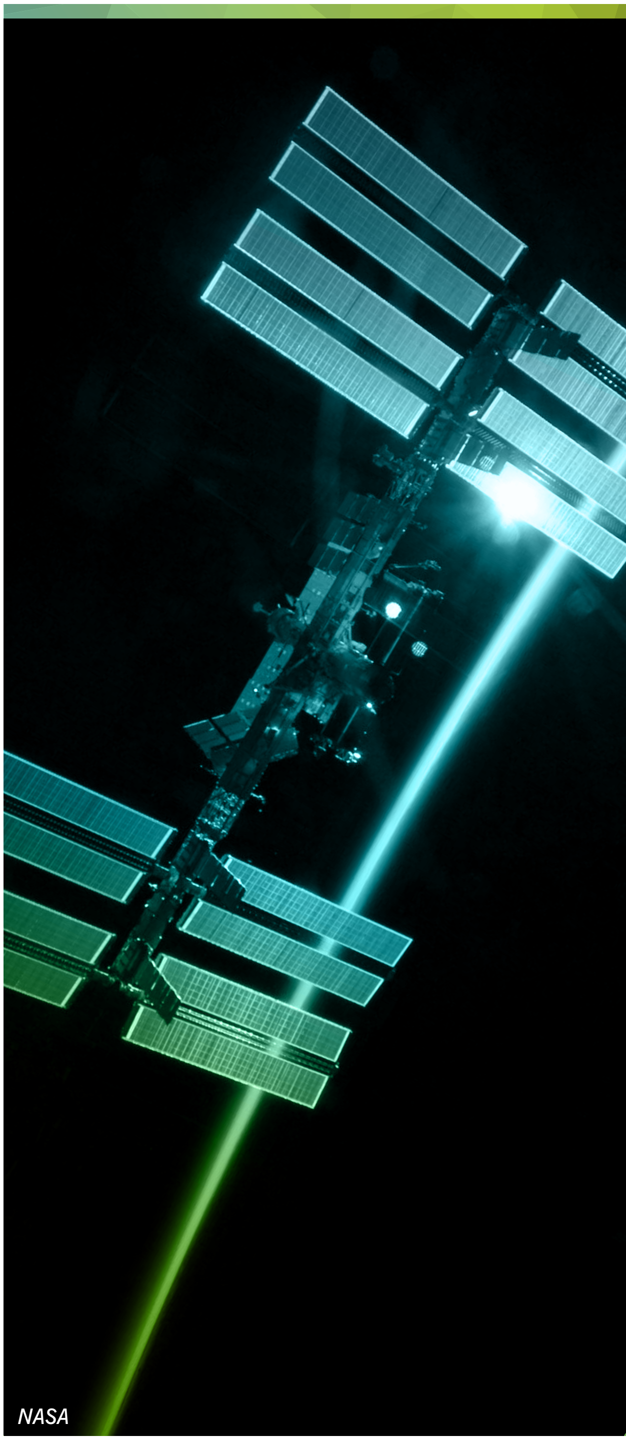
Recommendations

NASA, the ISS National Lab, the Space Station Explorers consortium, and the partner programs have launched, operated, and sustained a revolutionary approach to STEM education. Through the programs presented here, 2.4 million students have participated in an ISS-based experiment. This is a remarkable shift from the primarily outreach-based models of the past to a more impactful model directly involving students in experiments using the ISS.

In a sense, these programs have already defined and embarked on their future path. They have established themselves as viable, have working curriculum, and have found ways to be self-sustaining over multiple years. They have also established their appeal and impact on participating students. These programs will proceed on their merit and momentum.

In addition, the study makes the following recommendations:

1. Continue exploring creative and novel ideas, pushing the boundaries of the current programs.
2. Lower the cost for participants and operations, with innovative approaches such as remote-controlled experiments and efficiently sized experiment kits.
3. Create more opportunities for large-scale participation and more hands-on learning for adjunct students.
4. Expand outreach and participation of low socioeconomic and other under-represented students.
5. Integrate professional development for these programs into universities and continuing education for teachers.
6. Continue work with the community of student experimenters to share ideas, support each other's work, and keep connected after completing the experiments.
7. Build integrated packages, such as Expedition Space Lab, that strengthen connections among the programs.
8. Enhance use of the Space Station Explorers website and social media to highlight success stories, provide useful links, and serve as a data hub for the ISS and student experiments.
9. Continue the workforce connections through mentors, internships, and other direct connections to the aerospace industry.
10. Connect to other STEM and space programs beyond the ISS, such as missions to the Moon and Mars, and the growth and development of what is now called the Artemis Generation.



NASA

Appendix

Program Descriptions

ARISS

Amateur Radio on the International Space Station

TALK WITH AN ASTRONAUT ON THE SPACE STATION.

EXPERIMENT DESIGN:

- Students ask original questions to an astronaut during a 10-minute ARISS contact.
- In-orbit equipment includes radio, power supply, and external antenna.
- Astronauts must be licensed hams—and do this during personal time.
- Program is managed by volunteer hams.
- ARISS was the first operational experiment, of any kind, on the ISS in November 2000.

2000
FIRST USE WITH THE ISS

440
TOTAL U.S. CONTACT SESSIONS

WEBSITE	ariss.org
GRADES	3-12
SUBJECTS	Earth/Space, Language Arts, Technology, Engineering, Mathematics
WHEN	Ongoing
COST	Free

Frank Bauer
Amateur Radio on the International Space Stattion, Inc.
909 Metfield Road | Towson, MD 21286
ka3hdo@gmail.com

NASA

> *"ARISS radio contacts continue our longstanding efforts to inspire, engage, and educate students in STEAM subjects and encourage them to pursue STEAM careers."*
>
> —FRANK BAUER, ARISS PROGRAM MANAGER

DESCRIPTION: Amateur Radio on the International Space Station (ARISS) is a program of the Radio Amateur Satellite Corporation (AMSAT), the American Radio Relay League (ARRL), the ISS National Lab, and NASA.The ARISS program provides hands-on learning about radio and electronics, culminating in the unforgettable experience of talking with an astronaut. Each year, ARISS works with dozens of schools and community groups around the world to host events called "contacts," in which students use amateur radio, also known as ham radio, to talk directly with crew members on the ISS. Students learn about life aboard the ISS and explore Earth from space through science and math activities. Local ham radio operators often provide hands-on activities for students to learn about radio and technologies involved with space communications.

15
AVERAGE HOURS PER STUDENT

11,330
AVERAGE U.S. STUDENTS PER YEAR

226,600
TOTAL U.S. STUDENTS

Ants in Space

STUDENTS OBSERVE AND COMPARE ANTS LIVING IN EARTH'S GRAVITY WITH THOSE LIVING ON THE ISS.


BAYLOR COLLEGE OF MEDICINE

> *"Understanding how ants search in different conditions could have applications for robotics."*
> —DEBORAH GORDON, ANTS IN SPACE PRINCIPAL INVESTIGATOR

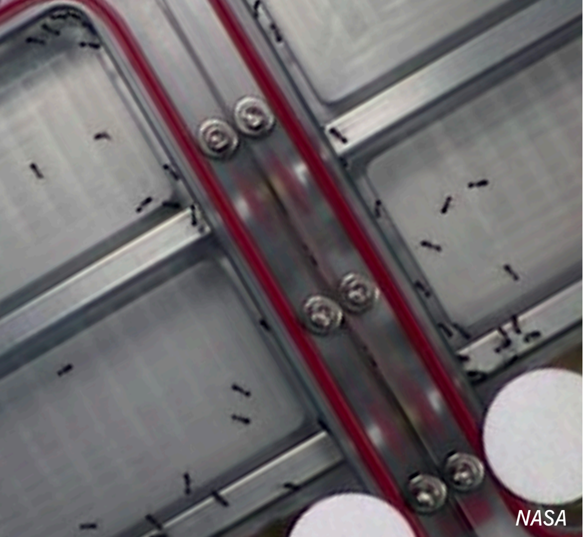
DESCRIPTION: Ants in Space is a life science investigation on the ISS developed in collaboration with Baylor College of Medicine's BioEd Online, BioServe Space Technologies of the University of Colorado, Stanford University, the ISS National Lab, and NASA. K-12 students examine and compare collective search behavior among common pavement ants *(Tetramorium caespitum)* in two different population densities, in microgravity, and in gravity conditions on Earth.

Activities in the downloadable "Ants in Space Teacher's Guide" are designed for use with multiple grade levels and as an observation activity for younger students. Students measure the distance of the ants' paths and observe how convoluted they are in the smaller and larger search areas of the ant habitat. They also determine whether, and how much, the ants' behaviors change between the higher- and lower-density search areas.

10
AVERAGE HOURS PER STUDENT

5,238
AVERAGE U.S. STUDENTS PER YEAR

15,713
TOTAL U.S. STUDENTS


NASA

EXPERIMENT DESIGN:

- Students construct their own 12 x 18 inch simple, inexpensive Earth-based ant habitats.
- Images and videos of ants living in microgravity aboard the ISS are available online for viewing and comparison with ground-based pavement ants.
- Data gathered from this study may help in the development of less expensive, more efficient strategies for search and exploration robots.

2014
FIRST USE WITH ISS

896
TOTAL GROUND KITS

WEBSITE	bioedonline.org/lessons-and-more/resource-collections/experiments-in-space/ants-in-space
GRADES	3-12
SUBJECTS	Biology, Mathematics
WHEN	Online
COST	Free

Dr. Nancy Moreno
Baylor College of Medicine
One Baylor Plaza | BCM411
Houston, TX 77030
nmoreno@bcm.edu

EARTHKAM

EXPERIMENT DESIGN:

- Students use web-based software to select target locations.
- Target lists are uploaded to an ISS computer.
- The ISS computer controls a camera in Destiny Lab's window.
- A new Nikon D5 camera provides high-res images (5588 x 3712 pixels).
- Students analyze the downloaded images.
- Anyone can explore the images via a web-based archive.

2001
FIRST YEAR ON THE ISS

717,665
TOTAL PHOTOGRAPHS

EarthKAM

WEBSITE	earthkam.org
GRADES	5-8
SUBJECTS	Earth Science
WHEN	4 sessions / year
COST	Free

Kay Taylor
US Space and Rocket Center
1 Tranquility Base | Huntsville, AL
kayt@spacecamp.com | 800.637.7223

Sally Ride ISS EarthKAM

STUDENTS SELECT TARGETS FOR A CAMERA ON THE ISS TO EXPLORE HOME PLANET EARTH.

NASA

> *"Real, current photographs of the Earth are powerful learning tools, especially when the students have a hand in creating them."* —ANNIE BOURQUE, TEACHER

DESCRIPTION: EarthKAM is an international award-winning program in which students photograph and analyze our planet from the viewpoint of the ISS. Using the internet, students control a digital camera on the orbiting laboratory to photograph Earth's cities, coastlines, mountain ranges, and other interesting geographical topography.

Students participate in three phases. First, they learn about the ISS, orbital paths, and Earth photography. Next they use web-based software to select the target locations on Earth. Lastly, they analyze the downloaded images—an essential part of the student experience. Students develop skills in image and data analysis while learning fundamental concepts about Earth systems and global change.

The sample image shows the coast of Chile. Analyzing images is an essential part of the student experience.

15
AVERAGE HOURS PER STUDENT

35,166
AVERAGE U.S. STUDENTS PER YEAR

668,159
TOTAL U.S. STUDENTS

MAGNITUDE.IO

EXPERIMENT DESIGN:

- The in-orbit ExoLab is a specialized 10 x 10 x 22 centimeter growth chamber.
- Sensors in the ExoLab capture, record, and report data such as luminosity, temperature, CO_2, humidity, and images of the experiment in microgravity.

2017
FIRST USE WITH ISS

429
TOTAL GROUND EXPERIMENTS

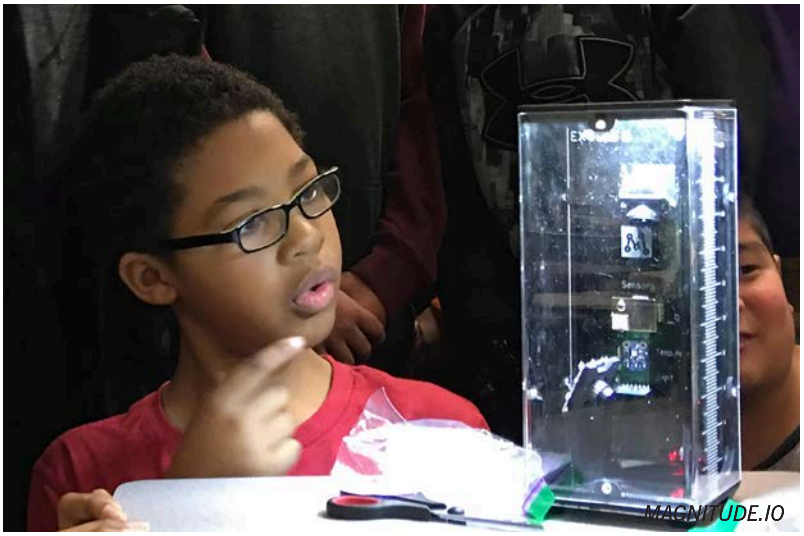
Magnitude.io
Powered by Curiosity

WEBSITE	magnitude.io
GRADES	6-8
SUBJECTS	Biology, Physical Science, Technology, Engineering, Mathematics
WHEN	Typically one or two flights per year
COST	$500 per school district

Ted Tegami
Magnitude.io
2247 6th Street | Berkeley, CA
ted@magnitude.io

ExoLab

STUDENTS INVESTIGATE THE EFFECTS OF MICROGRAVITY ON LIVING THINGS.



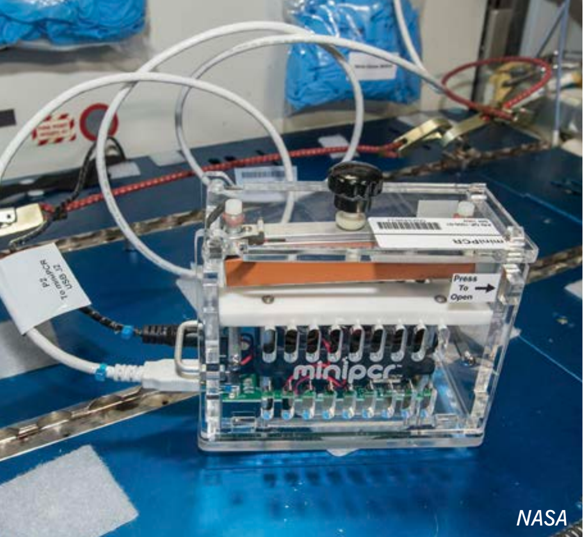
MAGNITUDE.IO

> *"Our driving inquiry is, 'What does life do without gravity?' The intention is to bring learning right to the very edge of discovery with several space missions each school year."*
> —TED TAGAMI, CHIEF EXECUTIVE OFFICER OF MAGNITUDE

DESCRIPTION: Magnitude.io, in partnership with Space Tango, Inc., created the **ExoLab**, an innovative experiment platform that brings together classrooms and the ISS in a collaborative investigation of the effects of microgravity on living things. The ExoLab is designed with lesson sequences for sixth through eighth grade. The Next Generation Science Standards-aligned curriculum engages students in experimental design, data collection and analysis, and communicating what they learn from their experiments.

Students conduct experiments, such as growing *Arabidopsis* plants, in their classroom ExoLab, while following along with a concurrent experiment on the ISS. The online Learning Management System provides educators access to real-time ISS experiment data, lessons, and student-friendly data analysis tools. Students analyze and compare the flight data with data from the ExoLab in the classroom.

4	12,099	35,311
AVERAGE HOURS PER STUDENT	AVERAGE U.S. STUDENTS PER YEAR	TOTAL U.S. STUDENTS



NASA

Genes in Space

STUDENTS DESIGN DNA EXPERIMENTS THAT ADDRESS A CHALLENGE IN SPACE EXPLORATION.

GENES IN SPACE

> *"Genes in Space inspires students to get involved in science and engineering…We are proud to extend this once-in-a-lifetime opportunity to students."*
> —**SEBASTIAN KRAVES, GIS CO-FOUNDER**

DESCRIPTION: Genes in Space (GIS) is a national STEM contest that challenges students in grades 7 through 12 to design DNA analysis experiments using the ISS National Lab, a platform for innovative research and technology development. The contest is a collaboration between miniPCR bio and Boeing with support from the ISS National Lab, Math for America, and New England Biolabs.

Students access online resources that help them draft their research proposal. Proposals are submitted online. Five GIS finalists are selected to receive mentoring from scientists from Harvard and MIT before presenting their proposals to a judging panel for a chance to launch their experiment to the ISS. The GIS national winner attends Space Biology Camp to prepare their experiment for space travel. After the experiment and postflight analyses, students help interpret findings and write up their results for publication.

14
AVERAGE HOURS PER STUDENT

1,684
AVERAGE U.S. STUDENTS PER YEAR

6,736
TOTAL U.S. STUDENTS

EXPERIMENT DESIGN:

- Astronauts use the miniPCR device and other biotechnology tools to prepare and run experimental samples.
- Polymerase chain reaction (PCR) is a powerful technology that amplifies a selected piece of DNA to generate millions of copies for further analysis.
- GIS loans educators miniPCR teaching toolkits to help students learn the PCR technology and prepare for the contest.

2016
FIRST USE WITH THE ISS

5
TOTAL EXPERIMENTS FLOWN

GENES IN SPACE

WEBSITE	genesinspace.org
GRADES	7-12
SUBJECTS	Biology, Technology, Engineering, Mathematics
WHEN	One flight per year
COST	Free

Dr. Sebastian Kraves
Amplyus, LLC
1770 Massachusetts Ave.
Cambridge, MA 02140
zeke@minipcr.com

Growing Beyond Earth

STUDENTS GROW AND TEST PLANT VARIETIES FOR FUTURE USE ON THE ISS AND BEYOND.

FAIRCHILD TROPICAL BOTANIC GARDEN

EXPERIMENT DESIGN:

- Plant data are submitted to NASA and can be used to help identify the hardiest and most nutritious plants suitable for further NASA testing—and identify possible candidates for spaceflight.
- The best plant varieties (i.e., wasabi mustard, extra dwarf pak choi, dragoon lettuce) are now in experimental trials at the Kennedy Space Center as possible candidate plants for growing in space.

2017
FIRST USE WITH THE ISS

429
TOTAL GROUND EXPERIMENTS

WEBSITE	fairchildgarden.org/science-and-education/science/growing-beyond-earth
GRADES	6-12
SUBJECTS	Biology, Chemistry, Engineering, Mathematics
WHEN	One program per school year
COST	Free

Amy Padolf
Fairchild Tropical Botanic Garden
10901 Old Cutler Rd.
Coral Gables, FL 33156
apadolf@fairchildgarden.org

NASA

> *"Partnering with NASA really got them excited about the scientific experiment."* —MARION LITZINGER, GROWING BEYOND EARTH PROJECT MANAGER

DESCRIPTION: Growing Beyond Earth (GBE) is a successful classroom-based citizen science research project supported and operated in partnership with NASA's Exploration Research and Technology program at Kennedy Space Center and the Fairchild Tropical Botanic Garden. The program is a series of authentic plant experiments conducted by students using equipment similar to NASA's Vegetable Production System on the ISS. GBE evolved out of NASA's efforts to find suitable crops for long-term space missions.

Schools receive a growth chamber that includes LED lighting, a capillary watering system, pots, soil, fertilizers, and seeds. Students follow research protocols using seeds from plants selected as potential candidates for long-term space missions. They plant the seeds in the class lab and nurture the seedlings from germination to adulthood, testing factors that may influence plant growth, flavor, nutrition, and biomass production.

10	6,017	18,050
AVERAGE HOURS PER STUDENT	AVERAGE U.S. STUDENTS PER YEAR	TOTAL U.S. STUDENTS

Higher Orbits

STUDENTS BUILD TEAMWORK AND LEADERSHIP SKILLS WHILE COMPETING FOR THE OPPORTUNITY TO SEND AN EXPERIMENT TO SPACE.


HIGHER ORBITS

EXPERIMENT DESIGN:

- Commercial Service Provider Space Tango, Inc., builds the student experiment in a 1U CubeLab with input from the team.
- After the experiment returns to Earth, students conduct qualitative observations and quantitative analysis.
- Higher Orbits teams have studied the effects of microgravity on radiation-absorbing fungi, pupating cabbage moths, and methane production of termites while in space.

2016
FIRST USE WITH THE ISS

10
TOTAL EXPERIMENTS FLOWN

WEBSITE	higherorbits.org
GRADES	9-12
SUBJECTS	Biology, Physical Science, Technology, Engineering, Mathematics
WHEN	Typically one or two flights per year
COST	Variable, depending on type of experiment

Michelle Lucas
Higher Orbits
PO Box 4092 | Leesburg, VA 20177
michelle@higherorbits.org


NASA

> *"Higher Orbits has inspired me to further pursue space science on my own through high school internship opportunities and other summer space-themed programs."*
> —HIGHER ORBITS STUDENT PARTICIPANT

DESCRIPTION: Higher Orbits is an out-of-school immersive, multiday program led by Higher Orbits, an educational nonprofit that uses the excitement of space exploration to engage students in STEM while building skills in creative arts, teamwork, communication, and leadership. During Higher Orbits events, high school students work with astronauts, scientists, and engineers. They design mission patches and perform hands-on collaborative activities for awards that culminate with a project intended for space. Participants experience science, technology, engineering, art, and math together.

Teams collaboratively define and design projects that contribute to human life in space and on Earth. The program encourages teamwork, leadership, and communication. Judges evaluate projects from Higher Orbits teams nationwide to determine a winning project that is launched to the ISS.

101	288	1,150
AVERAGE HOURS PER STUDENT	AVERAGE U.S. STUDENTS PER YEAR	TOTAL U.S. STUDENTS

High School Students United with NASA to Create Hardware (HUNCH)

STUDENTS BUILD HARDWARE AND SOFT GOODS FOR ASTRONAUTS ON THE ISS.

NASA

> *"Building products for NASA will open up a window of opportunities and help me meet my educational goals."*
> —**HUNCH HIGH SCHOOL STUDENT**

DESCRIPTION: HUNCH is a nationwide partnership between NASA and high school and intermediate/middle school students to build cost-effective hardware and soft goods both for use on the ISS and for training astronauts and flight controllers. These products improve the lives of the ISS crew and range from day-to-day personal items or tools to updated space station parts. There are several HUNCH project-based programs schools can get involved in: Design & Prototyping, Software, Hardware, Sewn Flight Articles, Video and Media, and Culinary.

NASA provides the materials, equipment, mentoring, and inspection oversight. Students get to play an active role in the space program, learning to use and apply three-dimensional software and welding, as well as drafting, prototyping, and basic architecture principles. Students learn 21st century skills and gain an awareness of STEM careers.

65	1,095	18,591
AVERAGE HOURS PER STUDENT	AVERAGE U.S. STUDENTS PER YEAR	TOTAL U.S. STUDENTS

HUNCH

EXPERIMENT DESIGN:

- Students have developed products to help astronauts live and work on the ISS that include stowage lockers, a crew quarter organizer, tools for use on a spacewalk, and nutritious foods.
- HUNCH provides volunteer opportunities for industry mentors to help guide students through the engineering design process.

2003
FIRST USE WITH THE ISS

281
TOTAL EXPERIMENTS FLOWN

WEBSITE	nasahunch.com
GRADES	6-12
SUBJECTS	Career Technical, Engineering, Mathematics
WHEN	During the school year
COST	Free

Blake Ratcliff
HUNCH
Johnson Space Center
2102 E. NASA Pkwy. | Houston, TX 77058
steven.b.ratcliff@nasa.gov

DAN BARSTOW

EXPERIMENT DESIGN:

- Students design experiments to fit in a 10 x 10 x 15-centimeter laboratory.
- Students program a micro-controller to control sensors, cameras, and motors, and to collect experiment data while on the space station.
- Students have investigated diverse topics including the life cycles of microorganisms, bacterial lag phase, and composting in space.

2014
FIRST USE WITH THE ISS

11
TOTAL EXPERIMENTS FLOWN

ISS NATIONAL LABORATORY

WEBSITE	issnationallab.org
GRADES	4-12
SUBJECTS	Biology, Physical Science, Technology, Engineering, Mathematics
WHEN	2014-2016 (discontinued)
COST	Free

Ken Shields
Center for the Advancement of Science in Space
6905 N. Wickham Rd. | Suite 500
Melbourne, FL 32940
kenshields@issnationallab.org

National Design Challenge

STUDENTS DESIGN, BUILD, AND SEND THEIR OWN EXPERIMENTS TO THE ISS.

DAN BARSTOW

"NDC is an opportunity for educators and civic leaders to take their communities to a whole new altitude—250 miles in space to the ISS National Lab." —KEN SHIELDS, CHIEF OPERATING OFFICER OF CASIS

DESCRIPTION: CASIS developed the National Design Challenge (NDC), a pilot STEM initiative in partnership with Nanoracks and Texas A&M University. NDC granted educators and students access to the research potential of the ISS National Lab. Students were fully immersed in experiment and engineering design processes as they conceptualized and executed experiments that operated on the ISS.

Flight projects were awarded based on a proposal process. Local mentors assisted students with designing, building, and coding the flight experiment. Experiments ran on station for 30 days before being returned to the students for postflight analysis. Students communicated with other teams about their project on the NDC website through blogs, technical documents, engineering notebooks, and design reviews, about the outcomes of their experiments.

195
AVERAGE HOURS PER STUDENT

55
AVERAGE U.S. STUDENTS PER YEAR

275
TOTAL U.S. STUDENTS

ORIONS QUEST

EXPERIMENT DESIGN:

- The CμRE mission studies whether cells grown in microgravity can serve as a model for cells in the human body on Earth and can be used to test the effectiveness and safety of a new cancer-fighting drug.
- Scientists have acknowledged schools in their scientific publications for their contributions to their research databases.

2004

FIRST USE WITH THE ISS

625

TOTAL GROUND EXPERIMENTS

WEBSITE	orionsquest.org
GRADES	4-12
SUBJECTS	Biology, Physical Science, Technology, Engineering, Mathematics
WHEN	Online
COST	Free

Peter Lawrie
Orion's Quest
1034 W. Ann Arbor Trail
Plymouth, MI 48170
plawrie@orionsquest.org

Orion's Quest

CHALLENGING AMERICA'S STUDENTS THROUGH THEIR PARTICIPATION IN SPACE-BASED RESEARCH.

ORIONS QUEST

> *"Orion's Quest is a lens through which students see NASA and their potential as future researchers."*
> —PETER LAWRIE, OQ EXECUTIVE DIRECTOR

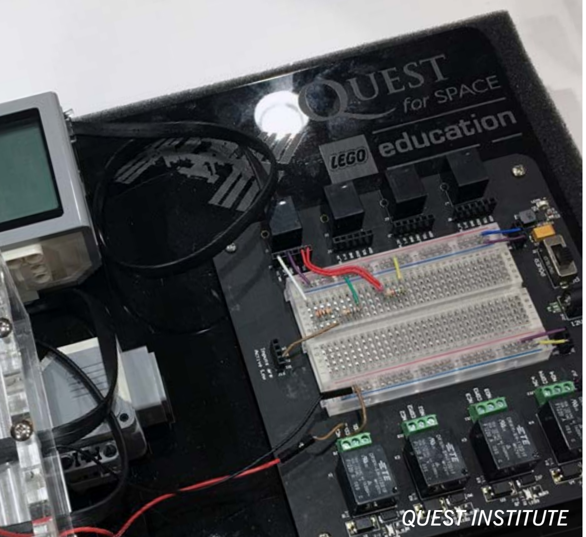
DESCRIPTION: Orion's Quest (OQ) is an internet-based, nonprofit education outreach program that utilizes authentic research currently conducted on the ISS to reach the next generation of explorers. Each OQ research program, or "Mission," includes curriculum based on national standards, a classroom activity reflecting the ISS research, images of research downlinked from the ISS to classroom computers, and ongoing support from OQ staff.

The photo or video analysis phase is manageable in scope for easy integration into the curriculum typically requiring 2-3 class periods. Live missions (those currently in space) typically take place during a single semester, while virtual missions are available online throughout the school year. Students submit their findings to scientists, making real contributions to world-class research aboard the ISS.

4
AVERAGE HOURS PER STUDENT

2,804
AVERAGE U.S. STUDENTS PER YEAR

41,852
TOTAL U.S. STUDENTS



QUEST INSTITUTE

Quest for Space Levels 1 and 2

STUDENTS INVESTIGATE HEAT TRANSFER EXPERIMENTS ON EARTH AND THE ISS.


QUEST INSTITUTE

> *"Space is a great motivator, and students are eager to tackle the engineering challenges to get their experiment to run on the ISS using our Quest for Space Program."*
>
> —DANNY KIM, CEO OF QUEST INSTITUTE FOR QUALITY EDUCATION

DESCRIPTION: The Quest Institute for Quality Education developed the Level 1: Inspiration Station and Level 2: Space Apprentice kits that enable students to create and run experiments on the ISS. Students learn age-appropriate concepts in mechanical, electrical, and software engineering.

The Level 1 kit is designed for elementary and middle school students. Students build experiments investigating three types of heat transfer—radiation, convection, and conduction—using heating bulbs, resistors, and temperature sensors. They write code for their experiment, uplink it to the ISS, and compare the space and ground data.

The Level 2 kit takes 7-12th grade students deeper into the world of space research. Building on the Level 1 experience, teams design their experiment on the more complex LEGO MINDSTORMS platform, uplink the code to the ISS, and conduct a comparative analysis of the downlinked data.

3
AVERAGE HOURS PER STUDENT

4,194
AVERAGE U.S. STUDENTS PER YEAR

16,775
TOTAL U.S. STUDENTS

EXPERIMENT DESIGN:

- Students hypothesize how microgravity might affect the three different types of heat transfer.
- Level 1: Inspiration Station introduces students to the Arduino environment and C programming language.
- Kits include 10-30 hours of curriculum support materials.
- Commercial Service Provider Space Tango provides access to the ISS in-orbit experiment.

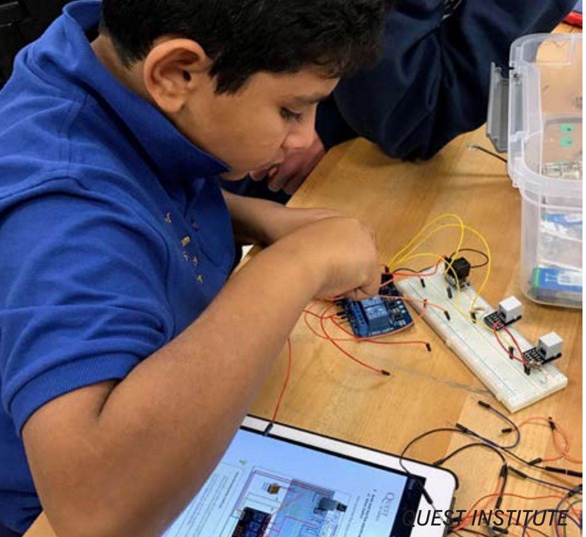
2016
FIRST USE WITH THE ISS

743
TOTAL UPLINKED EXPERIMENTS

QUEST for SPACE

WEBSITE	questforspace.com
GRADES	K-12
SUBJECTS	Physical Science, Engineering, Technology, Mathematics
WHEN	Year-round
COST	Level 1 – $299.99 Level 2 – $3,500

Daniel Kim
The Quest Institute for Quality Education
100 Skyway Drive | San Jose, CA 95111
dkim@thequestinstitute.com



QUEST INSTITUTE

EXPERIMENT DESIGN:

- Experiments run autonomously for 30 days in the ISS.
- Space Lab combines software programming, electrical engineering, mechanical engineering, project management, and teamwork.
- Students have investigated the effects of microgravity on plant health, bacterial growth, insect behavior, and radiation effects.

2011
FIRST USE WITH THE ISS

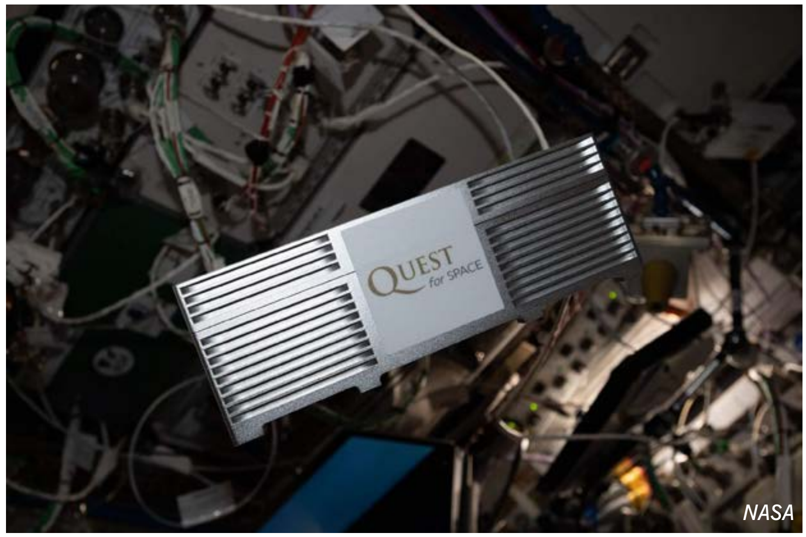
122
TOTAL EXPERIMENTS FLOWN

WEBSITE	questforspace.com
GRADES	7-12
SUBJECTS	Biology, Physics, Engineering, Coding
WHEN	Typically 1 flight per year
COST	$22,500

Daniel Kim
The Quest Institute for Quality Education
100 Skyway Drive | San Jose, CA 95111
dkim@thequestinstitute.com

Quest for Space Level 3: The ISS Space Lab

STUDENTS DESIGN, BUILD, AND SEND EXPERIMENTS TO THE ISS.



NASA

> *"Space research used to be out of reach for the youth but is now made possible through our Space Research program, which inspires the next generation of scientists."*
> —DANIEL KIM, QUEST INSTITUTE DIRECTOR OF INNOVATION

DESCRIPTION: The Quest Institute for Quality Education developed the Level 3: The ISS Space Lab, its most advanced student project for middle, high school, and college students. Students design an experiment and, with the help of technical mentors, design and build custom hardware to house their experiment in a mini laboratory. Students program a microprocessor to operate the experiment and collect data while on the ISS. They analyze the results of their postflight experiments and compare those results to their ground experiment.

The Level 3: Space Lab is designed to be self-paced during a nine-month school year. It can be structured as a classroom or out-of-school program. Professional development sessions are held in the summer for lead teachers and students, school administrators, and mentors to ensure the team is fully prepared to begin their projects at the start of the school year.

200	162	1,464
AVERAGE HOURS PER STUDENT	**AVERAGE U.S. STUDENTS PER YEAR**	**TOTAL U.S. STUDENTS**


DAN BARSTOW

Space Station Academy

STUDENTS GO ON A VIRTUAL MISSION TO THE ISS.


NASA

> *"Through this exciting program, students build STEM skills, gain a new perspective on Earth, and better understand the important work being done on the ISS."*
> —CAROL DEFURIA, PRESIDENT AND CEO OF VHS LEARNING

DESCRIPTION: Space Station Academy is an immersive, online program developed through a partnership between VHS Learning and CASIS that provides both formal and informal learning opportunities for students. Students become "cadets" as they go on a virtual mission to the ISS, participating in realistic training and in-orbit exercises, experiencing life as an astronaut, and observing Earth from space. Options within this program include:

Science from Space (grades 7-10): Semester science course teaching key STEM concepts (15 weeks, .5 credits)

Mission to the ISS (grades 6-12): Cohort-based, facilitated informal learning opportunity (4 weeks)

Mission to the ISS (grades 4-12): Blended course for integration into classroom instruction (10 modules)

Mission to the ISS (grades 6-12): Consolidated version, freely available online to be used independently

EXPERIMENT DESIGN:

- Cadets access data within images on the Windows on Earth website to determine location and make observations that lead to scientific questions about our planet.
- Cadets submit a Mission Report reflecting on how their mission has influenced their perspective of Earth.
- VHS Learning provides online instructors as well as training for educators and facilitators of out-of-school organizations.

2015
FIRST USE WITH THE ISS

1,171
TOTAL CADETS TRAINED

VHS Learning

WEBSITE	go.thevhs.org/spacestationacademy
SUBJECTS	Earth and Space Science, Technology, Engineering
WHEN	Online
COST	Varies per option

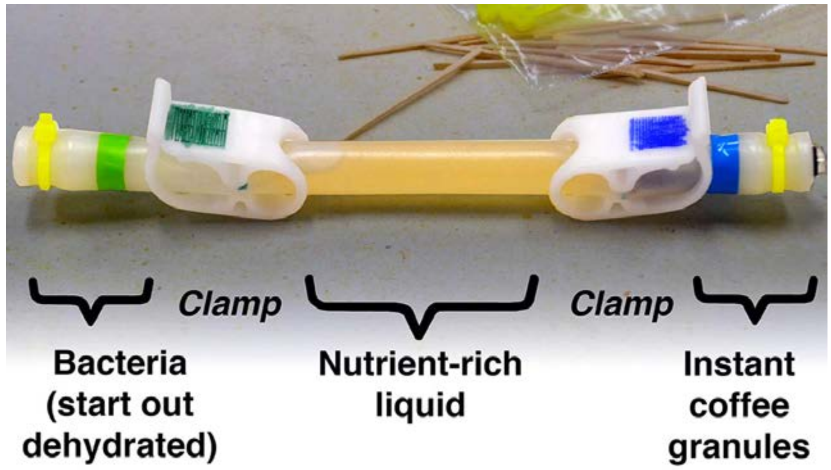
43	234	1,171
AVERAGE HOURS PER STUDENT	AVERAGE U.S. STUDENTS PER YEAR	TOTAL U.S. STUDENTS

Carol DeFuria
VHS Learning
4 Mill & Main Place | Suite 510
Maynard, MA 01754
cribeiro@vhslearning.org

NCESSE

Student Spaceflight Experiments Program

STUDENTS FLY EXPERIMENTS THAT MIX SUBSTANCES IN A TUBE TO TEST THE EFFECTS OF MICROGRAVITY.



NCESSE

> *"Student teams design a real experiment, propose for a real flight opportunity, experience a formal proposal review, and go through a NASA flight safety review."*
> —JEFF GOLDSTEIN, PROGRAM DIRECTOR FOR SSEP

DESCRIPTION: The Student Spaceflight Experiments Program (SSEP) was launched by the National Center for Earth and Space Science Education in strategic partnership with Nanoracks LLC. SSEP embraces a Learning Community Model for STEM education. Students design and propose authentic microgravity experiments for the ISS National Lab. Each participating community, generally a school district or town, conducts its own experiment design competition immersing hundreds of students in the research experience. The student proposals go through a formal 2-Step Review process, and an SSEP National Review Board selects one proposed experiment from each community to go to the ISS.

Student experiments are operated in flight certified hardware call a MixStix. After the experiments are conducted on the ISS, they are returned to students to analyze and compare with their ground experiments.

38
AVERAGE HOURS PER STUDENT

19,261
AVERAGE U.S. STUDENTS PER YEAR

173,352
TOTAL U.S. STUDENTS

EXPERIMENT DESIGN:

- A MixStix is a silicone tube, approximately eight inches long, with clamps to separate the compartments. Astronauts open the clamps to start and stop the experiment.
- Students investigate diverse topics including seed germination, crystal growth, food studies, and cell biology.
- Teams present their research at the SSEP National Conference that is held annually at the Smithsonian National Air and Space Museum.

2011
FIRST USE WITH THE ISS

281
TOTAL EXPERIENTS FLOWN

WEBSITE	ssep.ncesse.org
SUBJECTS	Biology, Physics, Chemistry, Technology, Engineering, Mathematics
GRADES	5-12
WHEN	One mission per year
COST	$22,000 per community

Jeff Goldstein
National Center for Earth and Space Science Education
PO Box 2350 | Ellicott City, MD 21041
301.395.0770 | jeffgoldstein@ncesse.org

Tomatosphere

STUDENTS GROW SEEDS THAT FLY IN SPACE.

FIRST THE SEED FOUNDATION

> *"Tomatosphere gives students real-world problem solving and critical thinking integrated with life and seed science."*
>
> —ANN JORSS, CHIEF OPERATING OFFICER OF FIRST THE SEED FOUNDATION

DESCRIPTION: Tomatosphere is an award-winning, curriculum-driven program that uses the excitement of space exploration to teach the skills and processes of scientific experimentation and inquiry. First the Seed Foundation and the ISS National Lab work together to send tomato seeds to the ISS and bring them back to Earth for classroom use. Students investigate the effects of the space environment on plant growth and the challenges of meeting humans' needs on long-duration space missions, like a mission to Mars.

Educators register online to receive two packets of seeds, ground and space seeds. Students plan and perform an experiment to compare the germination rates of the two groups of seeds. The experiment is a "blind test," meaning that the educators and students do not know which group of seeds flew in space until they submit their experimental results to Tomatosphere.

3
AVERAGE HOURS PER STUDENT

74,414
AVERAGE U.S. STUDENTS PER YEAR

1,413,858
TOTAL U.S. STUDENTS

NASA

EXPERIMENT DESIGN:

- Tomatoes were selected because they provide wholesome nourishment as well as purified water through evaporation from their leaves.
- Students can experiment with different kinds of growing medium, such as regolith that simulates soil on Mars and hydroponics that use soil-free growing mediums.

2001
FIRST YEAR ON THE ISS

7,300,000
TOTAL SEEDS FLOWN

TomatoSphere

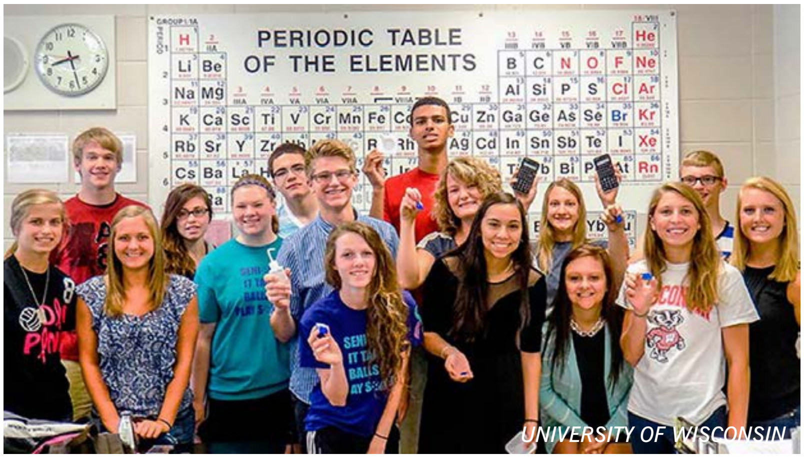
WEBSITE	firsttheseedfoundation.org/tomatosphere
GRADES	K-12
SUBJECTS	Biology
WHEN	Typically 1 flight per year
COST	Free

Ann Jorss
First the Seed Foundation
1701 Duke St. | Suite 275
Alexandria, VA 22314
ajorss@betterseed.org

NASA

Wisconsin Space Crystal

STUDENTS GROW CRYSTALS ON THE ISS.



UNIVERSITY OF WISCONSIN

> *"The Wisconsin Space Crystal Mission experience motivates the student participants to apply themselves in new areas and grow as scientists."* —ILIA GUZEI, PH.D., DIRECTOR OF CRYSTALLOGRAPHY AT THE UNIVERSITY OF WISCONSIN-MADISON

DESCRIPTION: The Wisconsin Space Crystal Growing Competition is a scientific, hands-on experience for middle and high school students hosted by the University of Wisconsin-Madison Chemistry Department's Molecular Structure Laboratory. The goal is to grow the largest and highest-quality single crystal. Selected competitors are provided the opportunity to grow their crystals in microgravity aboard the ISS National Lab.

A successful crystallization experiment produces high-quality single crystals both in the student lab and in space. Once the experiment is in orbit, the students monitor it while performing the companion ground reference experiment. Working in teams, students learn about crystallization techniques and the advantages of using microgravity for crystal growth studies, comparing data from crystals grown on the ISS with ground-based results.

12
AVERAGE HOURS PER STUDENT

550
AVERAGE U.S. STUDENTS PER YEAR

1,100
TOTAL U.S. STUDENTS

EXPERIMENT DESIGN:

- Middle school students grow copper (II) sulfate crystals, and high school students grow potassium dihydrogen phosphate crystals.
- The crystal sample flight bags launch at ambient temperature and are transferred to a 2° Celsius refrigerator once on the ISS for a growth period of seven days.
- The crystals are investigated by analytical means and single-crystal X-ray diffraction once back on Earth.

2018
FIRST USE WITH THE ISS

2
TOTAL EXPERIMENTS FLOWN

WEBSITE	wicgc.chem.wisc.edu
GRADES	6-12
SUBJECTS	Chemistry, Physical Science, Engineering
WHEN	One flight per year
COST	Free

Ilia Guzei
University of Wisconsin-Madison
2124 Chemistry Building | 1101 University Ave.
Madison, WI 53706
iguzei@chem.wisc.edu

Zero Robotics

STUDENTS CODE ROBOTS ON THE INTERNATIONAL SPACE STATION.


NASA

> *"Zero Robotics seeks to inspire students to pursue an education in the STEM subjects."*
> —KATIE MAGRANE, ZERO ROBOTICS PROGRAM MANAGER

DESCRIPTION: Developed by the Massachusetts Institute of Technology (MIT), Zero Robotics is a competition in which middle and high school students program a squadron of miniature robotic satellites that operate inside the ISS.

Students write code to control the speed, direction, and rotation of the satellites to solve a specific challenge. Teams face off in virtual trials to test their algorithms. The middle school program uses a dynamic graphic interface to help students learn to write code, while high school teams write straight C++ code. Teams that make it through the virtual simulations to the finals compete in a live tournament where astronauts load student-developed code onto the satellites onboard the ISS. Astronauts serve as referees, and everything is streamed in real time to student viewers on Earth.

With NASA's second-generation free-flying robotic system, Astrobee, now on station, Zero Robotics is transitioning the competition from using Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) to the new Astrobee satellites.

83
AVERAGE HOURS PER STUDENT

1,206
AVERAGE U.S. STUDENTS PER YEAR

13,263
TOTAL U.S. STUDENTS


ZERO ROBOTICS

EXPERIMENT DESIGN:

- The Zero Robotics challenge is different every year. Whether it's cleaning up space debris (ECO-SPHERES), establishing a GPS System for Mars (SPACE-SPHERES), or drilling for microbial samples on Enceladus, one of Jupiter's moons (LIFE-SPHERES), students write code that reflects current research and work being conducted in space.
- High school tournament: An international event that occurs each fall
- Middle school program: A five-week summer program

2009
FIRST USE WITH THE ISS

525
TOTAL UPLINKED SESSIONS

WEBSITE	zerorobotics.mit.edu
GRADES	6-12
SUBJECTS	Technology, Engineering, Mathematics
WHEN	Typically 2 missions per year
COST	Free

Katie Magrane
Innovation Learning Center
77 Massachusetts Ave.
Cambridge, MA 02139
katie@massilc.com