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The Solar Terrestrial Relations Observatory (STEREO) Education and Outreach (E/PO) Program

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Abstract The STEREO mission's Education and Outreach (E/PO) program began early enough its team benefited from many lessons learned as NASA's E/PO profession matured. Originally made up of discrete programs, by launch the STEREO E/PO program had developed into a quality suite containing all the program elements now considered standard:

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education workshops, teacher/student guides, national and international collaboration, etc. The benefit of bringing so many unique programs together is the resulting diverse portfolio, with scientists, E/PO professionals, and their education partners all of whom can focus on excellent smaller programs. The drawback is a less cohesive program nearly impossible to evaluate in its entirety with the given funding. When individual components were evaluated, we found our programs mostly made positive impact. In this paper, we elaborate on the programs, hoping that others will effectively use or improve upon them. When possible, we indicate the programs' effects on their target audiences.

Keywords Education · Outreach · Sun: coronal mass ejections (CMEs) · Sun: magnetic fields · Sun: particle emission · Sun: solar-terrestrial relations

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1 Introduction

While the STEREO spacecrafts and instruments were being built and tested for launch and operation, the STEREO Education and Public Outreach (E/PO) program was preparing future teachers, in-service teachers, students, science centers, and the general public for the launch and subsequent science coming from STEREO. This article describes these prelaunch E/PO activities and provides a section of a much larger paper in this issue of *Space Sciences Review* describing the STEREO Mission and Science. Reflecting on these activities, we hope to provide scientists who have not participated in E/PO activities with an understanding of E/PO, to share with future E/PO professionals some of the paths to the final product or program, and to let solar and space scientists and E/PO professionals know what E/PO resources are available from the STEREO mission.

1.1 Education and Public Outreach at NASA's Science Mission Directorate

NASA's role in education is often under discussion and review. In 1996 the NASA office, then known as the Office of Space Science (OSS), brought together scientists and educators and developed a plan to implement a bold and innovative approach to education and public outreach (E/PO) (OSS-SSAC E/PO Task Force Report 1996). This approach operated on the premise that:

> …achieving genuine success in affecting the quality of science, technology, engineering, and mathematics education in America will not be won through short-term activities with immediate results, but rather through a long-term commitment requiring a sustained effort in education and public outreach (SSAC E/PO Task Force Report 2003).

The idea was "to more effectively engage and involve the space science community in support of the nation's future interests and needs in science education" (Cooper et al. 2004). Since then, NASA has required that each satellite mission use a small percentage (around 1%) of the mission budget, excluding launch costs, for E/PO projects.

In order to help these OSS E/PO projects focus on customer needs (i.e., the needs of teachers, students, and the public), Morrow (2000) published a short report on the categorization of E/PO activities and materials. These three categories are: formal education, informal education, and public outreach. Formal education seeks to reach grades K-14 teachers and students in relation to the classroom. Informal education seeks to engage the public in science education settings—such as after school programs, scouting organizations, and science centers. Public outreach is meant to reach the public in their own environment, such as through educational television shows, games, web pages, or radio shows. Morrow (2000) pointed out that many scientists do not understand the distinction between public relations (PR) and E/PO public outreach. The difference is mostly in the intent: E/PO public outreach aims to educate the public further about science, whereas PR conveys the work done at NASA.

Part of effective E/PO is ensuring the scientists are able to connect their work and research with educators and the public. NASA's mandate that a small percentage of space science mission budgets fund formal, informal, and public outreach E/PO opportunities—closely tied to the NASA satellite missions—is one way to ensure that scientists are more directly involved in educating students, teachers, and the public. A poll of scientists in 2001 found that 42% engaged in no public outreach (NSB Report 2004). More scientist participation in public outreach can ensure that the "customers" of the E/PO program (such as teachers or the public attending science centers) receive correct scientific information based on the most current data and learn about the most recent NASA science discoveries. In 2002, the Solar and Space Physics Survey Committee of the National Research Council found that "NASA-funded E/PO projects encourage and permit researchers to collaborate with educators on a wide variety of educational activities related to solar and space physics, many of which have a substantial impact on public awareness of issues in solar and space physics and their link to broader science and technology concerns." (SSPSC/NRC 2002). This indicates that, in general, having scientists work with educators in NASA's space science programs is a successful model.

Accurate space science information and inspirational discoveries also potentially help ameliorate the predicted upcoming crisis in providing a scientifically and technically literate workforce for the twenty-first century. In 2004, the National Science Foundation (NSF) reported "US 12th graders recently performed below the international average for 21 countries on a test of general knowledge in mathematics and science" (NSB Report 2004). NSF also reported "in 1999, only 41% of US 8th grade students received instruction from a mathematics teacher who specialized in mathematics; considerably lower than the international average of 71%" (NSB Report 2004). This science literacy crisis has alarmed so many scientists, educators, and technologically dependent companies that senators of the Committee on Energy and Natural Resources and representatives of the House Committee on Science asked the National Academies for a report on a strategy to enhance the science and technology enterprise so the U.S. can successfully compete, prosper, and be secure in the global community of the twenty-first century (NAS Report 2005).

The NSB Report (2004) furthermore examined the public understanding and support for science and technology (S&T). The report's findings help us to understanding what the public needs in terms of science education, as well as how the public continues to learn about science outside of school. The report provided the following information.

– Although Americans express strong support for S&T, they are not very well informed about these subjects.
– The popularity of science museums and books suggests that people are interested in science even though they may not be following science-related news.

– The Internet is the preferred source for people seeking information about specific scientific issues.

This NSB Report (2004) underscores the needs facing the nation and provides some guidance on how NASA E/PO programs can help both students and the public.

The 2006 review criteria for most NASA E/PO proposals were adapted to address some of the needs of students and public mentioned in the NSF report. Proposals must focus on the needs of the audience associated with the educational activities or products. Partnerships must be developed with other education institutions in order to leverage the small amount of money NASA provides for E/PO programs, as well as to ensure that the developed activities and products are sustained after the NASA funding is gone. Partnerships also allow for a broader dissemination of the work done by the scientists and E/PO specialists. Furthermore, all proposed efforts must describe how they will be evaluated to determine if the goals of the proposal have been met. Demonstrable goals include how NASA content, people, or facilities will be used; how the proposed activities and products will attract diverse populations to careers in science, technology, engineering, and mathematics (STEM); and how the proposed program will involve underserved and/or underutilized groups in STEM. STEREO E/PO was not reviewed under these criteria, but as the STEREO E/PO program has matured with the NASA E/PO profession, several of the STEREO E/PO programs made an effort to meet these criteria.

1.2 STEREO Education and Public Outreach Program

In 1999, each STEREO instrument team—In-situ Measurements of Particles and CME Transients (IMPACT), Plasma and Supra-Thermal Ion Composition (PLASTIC), Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI), and STEREO Waves (SWAVES)—submitted an E/PO proposal for 1% of the respective instrument budget. These instrument teams, together with the STEREO project office at Goddard and E/PO efforts of the spacecraft team at the Advanced Plasma Laboratory (APL), make up the STEREO E/PO program. Because of the array of groups in this program, many different types of programs and resources have been developed. However, until close to launch these groups operated completely independently. Near and after launch, the various STEREO E/PO groups began to share their products and programs, enhancing the independent programs developed by each group. This paper will reflect on this "loose federation," while providing an overall view of the program.

After reviewing the intent and evolution of these different programs, it is clear that the STEREO E/PO program had several goals for the E/PO activities in Phases B, C, and D before launch:

1. In formal education, we aimed to educate teachers and students nationally about the science of the Sun, space science technologies, and mathematical tools used in space weather research.
2. In informal education, we aimed to inspire science center and planetarium attendees and artists to learn more about solar science and STEREO.
3. In public outreach, we aimed to share the STEREO mission and its science with the public, primarily through the Internet and radio.
4. We aimed to inspire a variety of underserved groups, in particular girls, Hispanics, and African Americans, to learn more about solar science and magnetism.

STEREO scientists, engineers, and E/PO specialists have been directly involved all of the STEREO activities and products. Details of the programs designed to meet these goals are described in the following. Program evaluations results are shared when available. (Note that the URLs for websites referenced throughout this paper can be found in Sect. 4.)

2 Formal Education Activities

From discussions with teachers and written feedback from educators in our formal education activities, it is clear that we are providing some needed content in physics, using the Sun as inspiration. Many of these teachers are not trained specifically in science, and even fewer in physics. As mentioned earlier, the U.S. is well behind the rest of the world in STEM education. We cannot claim to have solved this huge problem, but we have helped by directly providing more than 1,000 pre- and in-service teachers and hundreds of students with content and hands-on lessons to enhance their teaching and learning about the Sun, magnetism, gravity, the electromagnetic spectrum, atoms, orbits, and engineering. We have done this through: (1) a one-semester undergraduate, pre-service teacher class about physics using the Sun as the focus of the classes, held once a year for four years; (2) four years of in-service teacher professional development (PD) workshops, which varied in length from one-hour to two-day workshops; (3) STEREO-developed middle school, high school, and undergraduate lessons, and (4) special events for middle and high school students and their teachers.

2.1 Pre-service Teacher Professional Development Workshops

Two simultaneous events resulted in the creation of the Teachers of Physical Science (TOPS!) program, a physics course designed to teach pre-service teachers basic physics concepts using NASA research on the Sun as inspiration: (1) The education department at the Catholic University of America (CUA) in Washington, D.C., needed a course on physical science for their pre-service teachers. (2) After talking with teachers at a variety of education and outreach workshops, the STEREO team at the nearby Naval Research Laboratory (NRL) realized that teachers needed more background knowledge about physics than they got in the short teacher professional development (PD) workshops. Through a connection between these institutions, TOPS! was born. It was designed to produce top teachers of physical science by leveraging a collaboration between the departments of Education and Physics at the CUA, the NRL, and the NASA Goddard Space Flight Center. Together, these partners developed a basic physical science course in the Physics Department at CUA to meet the specific needs of undergraduate, pre-service teachers majoring in Early Childhood and Elementary Education.

The course, called "Sun and Earth: Concepts and Connections," is a four-credit physics course in which the wonders of Sun–Earth Connection physics serve as a vehicle for teaching a limited number of the fundamental principles of physical science. Hands-on experiments, computer simulations, analysis of real NASA data, and vigorous seminar discussions are blended in an inquiry-driven curriculum to instill confident understanding of basic science and modern, effective methods for teaching it. (See the course outline in Fig. 1). Three faculty members from physics, education, and research teach the course simultaneously to provide students with perspectives from all three realms.

Both course content and the pedagogic techniques reflect and specifically reference the *National Science Education Standards* (NSES) (NRC 1996) and the *Benchmarks for Science Literacy* (AAAS 1993). Through Internet connections and the participation of space scientists in classroom discussions, future teachers work with real data from NASA satellites to understand how key scientific concepts are expressed on local, global, and astronomical scales. Applying these principles to various aspects of Sun–Earth Connection physics

Fig. 1 Course Outline for the TOPS! 4 credit physics course

Magnetism and Gravity: *Force Fields* —Mass and electrical charge distort space and shape the universe.

Our Star, the Sun: *Anatomy of the Sun*—Sunspots, solar magnetism, solar layers

Sun–Earth gravitational interaction maintains Earth in its orbit: *1. Newton's conquest: the universal gravitational force*—forces and motion, Newton's laws. *2.The solar system was formed by and is ruled by gravity*—gravitational condensation, atoms, stars, rotations, and orbits in the solar system

Electromagnetic radiation transports energy from the Sun to the Earth: *1. Electromagnetism: Triumph of 19th century science*—charge, currents, circuits, bar magnets, electromagnet. *2. Waves of energy: heat, light, and color. Maxwell's rainbow*

Geology and Geography—Earth as we know it, and what we make of it: 1. *Earth in the solar system*—rotation (day and night) and orbital motion (seasons and years). 2. *Structure of our planet*—core, mantle and lithosphere; oceans and continents; tectonic motions and disruptions; magnetic footprints on the ocean floor. 3. *Pressure and temperature*—the atmosphere, ionosphere, and "empty" space. *4. Earth's magnetic field*—Gilbert's *De Magnete*: a masterpiece of analysis

Swimming in the Sun—the solar wind showers Earth with electrons and protons—1. *How big is the Sun really?* Gravity and our place in the galaxy. *2. How hot is the Sun and how hot is that???*—our star's vast atmosphere, solar storms, aurorae, and geomagnetic storms.

Fig. 2 TOPS! future K-8 teachers learn design and characteristics of a simple telescope and how to use it for direct observations and projection of solar images

illustrates how a genuine understanding of even the simplest of physical principles can illuminate and integrate our vision of the world around us. In Fig. 2, teachers literally change their view of the world around them, using simple solar telescopes. After four years, this one-semester course is now required for all incoming General Education majors at CUA, leading to a course that will be sustained for years to come.

The program exposes these nonscience students to the excitement and satisfaction of research, with enough emotional impact and sufficient contextual skill that most are enabled to inspire and inform the next generation of students. One teacher, who took the course

Fig. 3 Teacher comments from workshop evaluations

"I learned a tremendous amount of science and also some great teaching tools."
"I like the different displays to demonstrate the magnetic fields."
"It was one of the best workshops I have ever attended."
"Thank you for the CD and other materials."
"What are the practical uses for students—especially for inner city kids?"
"I would have loved an electronic copy of the PowerPoint presentations."
"Just needed more time for me to understand it enough to teach it well."
"I am glad I attended this (workshop) a second time. I feel like I have a much better grasp now."

in spring 2005, says what she learned in the course proved invaluable when she did her student teaching in fall 2006, at a public charter school in the Columbia Heights section of Northwest Washington, DC. Another teacher claimed in an interview after she graduated, "Without a doubt, Sun and Earth changed the way I see science." Several teachers have contacted the TOPS! program to ask for additional STEREO and NASA materials to use in their classrooms.

The STEREO team at NRL aims to expand the TOPS! program to a broader collaboration in the Washington, DC, area teacher preparation community through partnerships with other universities. This team also plans to develop a *Classroom Teacher's Guide to the Sun*, a manual for teaching the Sun at K-8 levels and companion to the TOPS! teacher education course. The SECCHI E/PO program at the Naval Research Laboratory (NRL) led this endeavor.

2.2 In-Service Teacher Professional Development Workshops

The STEREO E/PO program at the University of California, Berkeley (UCB) has partnered with several other NASA mission E/PO programs and the Sun–Earth Connection Education Forum (SECEF) to hold teacher professional development (PD) workshops around the country. In the STEREO prelaunch years, 1,220 teachers participated in classroom lessons and science content on magnetism, the Sun, geospace, and the STEREO mission in 29 in-service PD workshops. These workshops were either part of national or state science teacher conferences, such as the National Science Teacher's Association (NSTA) conference, or part of an ongoing effort to train teachers who come to the Space Sciences Laboratory (SSL) at UCB. The PD workshops varied from one-hour workshops to two-day workshops for graduate credit from California State University East Bay. In most of these workshops, the teachers modeled selected activities from the IMPACT E/PO teacher guides described in Sect. 2.3. Evaluation questionnaires indicated that more than half of these teachers had large populations of Hispanic and African-American students in their classrooms. The evaluations, developed with the help of professional evaluators, also indicated that more than 70% of participants in all of the workshops indicated they were "very likely" or "certain" to use the presented materials in their classrooms. However, 50% of the teachers indicated that lack of money to buy magnets, compasses, batteries, and circuits would be a difficult barrier to implementing the magnetism lessons in their classroom. A sampling of some of the teacher feedback demonstrates the successes and challenges of these workshops, as shown in Fig. 3. These types of teacher workshops will continue throughout the life of the STEREO mission and will continue to be improved using the teacher feedback. Information on when and where these workshops will be held can be found on the IMPACT E/PO website.

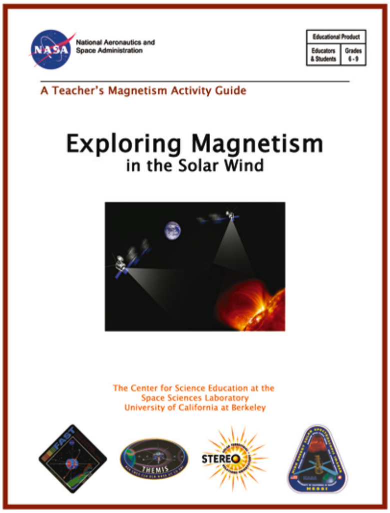

Fig. 4 Exploring Magnetism in the Solar Wind Teacher's Guide cover

2.3 Development of Classroom Materials

The STEREO E/PO team has developed and created various products for the classroom: teacher guides and classroom activities, web pages for use in the classroom, CD-ROMs and a 3-D poster with STEREO science and mission content, STEREO satellite cut-out design booklets, and STEREO flyers. The CD-ROMs, poster, satellite booklets, and flyers are also meant for the public and are described in Sect. 4.2 for the Public Outreach programs. Materials were also developed and created for the Space Academy and the Space Weather Challenge mentioned in Sect. 2.4. The team felt the creation of these products was important to the STEREO E/PO in order to bring the latest science and mission information into the classroom. Teachers have told STEREO E/PO scientists that students are more engaged in science when they know they are being taught the most up-to-date science and feel that they are part of a NASA mission.

The STEREO E/PO team at the University of California, Berkeley (UCB) created two guides for middle school teachers, "Exploring Magnetism" and "Exploring Magnetism in the Solar Wind," which are sequential. The cover of the latter is shown in Fig. 4. The goal of the activities is that, through inquiry-based activities, students develop a deeper understanding of electromagnetism and engineering processes related to STEREO. In these guides, students map magnetic field lines around bar magnets, build circuits to map magnetic field lines around coils and explore the effects of increasing current and coil turns relevant to magnetic field strength, learn about the Sun–Earth connection through lecture, brainstorm a design to measure the Sun's magnetic field, and report on their design to their classmates.

These guides were in part developed using the concept of "backward design" (Wiggins and McTighe 1998). In backward design, assessment drives instruction, leading to a lesson with a built-in way to determine whether a student has actually learned these ideas. The lessons were tested in several classrooms and are tied to the NSES (NRC 1996). A panel of teachers and scientists reviewed these teacher guides as part of the NASA Education Product Review conducted by the Institute for Global Environmental Strategies (IGES). The guides were rated "Excellent" and were thus modeled with 41 NASA's teacher-educators in the Aerospace Education Services Program (AESP), Education Resource Center (ERC) educators, and broker/facilitators in November 2004. The AESP educators conduct teacher professional development around the country, so this opportunity allowed for a wide dissemination of these guides. The guides were also modeled and disseminated in the many teacher PD workshops discussed in Sect. 2.2. The IMPACT E/PO group led the development and printing of these guides. The printing of the guides was possible through a collaboration of several NASA mission E/POs. The full guides and activities are available online on the IMPACT E/PO web site (the URL is given in Sect. 4).

The STEREO/WAVES (S/WAVES) E/PO program has developed a series of classroom-oriented S/WAVES radio models. The simplest version is used to demonstrate the directionality of radio waves and how this permits triangulation of the sources. Using these models, teachers can help students learn about the following concepts in the given grade levels:

- (5–8) monopoles or linear dipoles: demonstrate *directionality* of (AM) radio waves, triangulation *measurement concepts*.
- (5–8) triad antenna (three orthogonal antennas, like the S/WAVES antennas) shows realistic spacecraft system; measurement of angles leads to investigation of basic *geometry & trigonometry*.
- (9–12) Model plus triad antenna equations provide motivation for *spherical trigonometry* and more advanced *algebraic equation solving*.

The STEREO project office E/PO at the Goddard Space Flight Center (GSFC) collaborated with the Living With a Star (LWS) E/PO Program to develop and implement classroom activities designed to educate middle school and high school students about STEREO and Sun–Earth Connection (SEC) Science and Engineering. These activities were designed as a science challenge for high school students and an engineering challenge for middle school students for the Fall 2005 semester. For the middle school engineering project, students constructed and balanced a model of the STEREO spacecraft, which was specifically developed by senior engineers for this E/PO activity. The science project challenged high school students to submit answers to challenging engineering questions. The final challenge included space weather and STEREO information and used resources created especially for this project. One hundred forty-six middle school and 28 high school groups registered for the challenge. Participants included 14 public and three private schools from the east coast and six public schools in Puerto Rico. Student groups submitted a final overview, detailing their successes and challenges with the project. The overview indicated that these students and their teachers now have a better understanding of STEREO SEC science and that they were eagerly awaiting the launch of STEREO and the resulting research to generate further classroom discussion. The LWS program facilitated the challenge information and resources, available through the LWS program office web site. (See Sect. 4.1 for the URL for this web site.)

2.4 Student-Focused Events

Students with their teachers from the metropolitan Washington, DC, area elementary and middle schools participated in a Space Weather Day on November 29, 2005, with more than 100 attendees. The day included hands-on activities by E/PO specialists and presentations by scientists. Students were taught about spectrometers, space radiation, and the effects of UV radiation. The activities were not only educational—evaluations indicated that it was also fun for the participants and provided them a unique NASA-based understanding of space weather. This Space Weather Day was a collaborative effort between the STP/LWS E/PO Program office, the STEREO program E/PO at the Goddard Space Flight Center (GSFC), Solar Dynamics Observatory (SDO), Space Environment Testbeds (SET), George Mason University, and the GSFC Visitor Center.

Fig. 5 Students and their teachers visiting the APL Academy

A similar but separate program, Space Academy, gives middle school students a behind-the-scenes look at actual space missions, such as STEREO, and introduces them to engineers and scientists working on NASA projects. Space Academy is held twice a year at the Advanced Plasma Laboratory (APL) in Laurel, Maryland with hands-on, minds-on experiences designed to inspire both students and teachers. Weeks before the event, students learn about a specific mission, its science theme, and space-related careers through classroom activities and videos developed by Discovery Networks and APL. The Space Academy program web site showcases these events and student activities. This web site can be found from the APL STEREO E/PO web site URL given in Sect. 4.

In October 2004, more than 100 Maryland middle school students and their teachers from four schools in three counties (Charles County, Harford County, and Montgomery County) participated in a daylong STEREO Space Academy. A photograph of the participants is shown in Fig. 5. The day included a student press conference, where the students—like real reporters in a real NASA press conference—posed questions to a panel of STEREO team members from NASA and APL. Students also had discussions with scientists and engineers at lunchtime and in hands-on science demonstrations. They toured APL's space facilities, where they saw the twin STEREO spacecraft under construction, and visited labs where the spacecraft were tested prior to launch.

Three lesson plans used as pre- and post-visit activities were created for this event and can be accessed from the APL STEREO E/PO web site. The STEREO Mission activity explains how the unique new data from the two STEREO spacecraft will be used to study the nature of coronal mass ejections (CMEs). This activity addresses the effect these powerful solar eruptions can have on Earth and on the lives of humans in space, and even on global climate over the long term. The Make your Own Stereograms activity has students use a camera to make their own set of stereograms that can be used to create a 3-D image with the homemade stereoscope. This activity also includes instructions for constructing a stereoscope. The Fact Finding, Discussion, and Analysis activity guides students through the APL STEREO web site to investigate more about the STEREO mission. APL, Comcast Cable, and the Discovery Channel sponsor the Space Academy series and STEREO E/PO at APL leveraged this series.

3 Informal Education Activities

The STEREO E/PO team's goal for informal education was to inspire science center and planetarium attendees, musicians, artists, and science enthusiasts to learn more about solar science and about STEREO in general. We set out to meet this goal by: (1) working with a small planetarium in New Hampshire to reach rural planetarium attendees, (2) working with the Sun–Earth Connection Education Forum during eclipses to bring STEREO mission engineering and science to museums across the country, and (3) inspiring and teaching musicians, artists, and science enthusiasts about STEREO and solar physics by changing silent data and graphs into interesting sounds.

3.1 STEREO in Science Centers and Planetariums

The goal of an in-depth partnership with the Christa McAuliffe Planetarium is creating public awareness and understanding of solar science, and to inspire and encourage young people to pursue careers in science and engineering. Through this partnership, the STEREO team at the University of New Hampshire (UNH) has created two planetarium shows, *Living with a Star* and *Breathing Space*, and helped to hold several events for the public. During the development of both shows, the planetarium gathered a focus group of teachers to find out what they thought was important for the students to learn. They also convened a focus group of high school students to find out what they thought would be important to know, and how they would like the science delivered (types of humor and ways of keeping their interest). In addition to these focus groups, the planetarium gathered questions from their patrons about the Sun. These needs assessments then informed the design of the two shows.

The *Living with a Star* planetarium show is a multimedia show, geared to grades 3–12 and general audiences, on solar science by way of a rocket ship flying into the heart of the Sun. In this show, the audience calls STEREO scientists and talks with them. Students indicated that interacting with the local scientists increased their own confidence in doing science. *Living with a Star* was complemented by *Sunbeams*, an exhibit on the spectrum and solar energy. The *Sunbeams* exhibit includes a model of the STEREO B spacecraft as an example of how spacecraft design includes solar panels as a power source. For the smaller children who cannot read, it was important to have someone available to help explain the spectrum and solar energy hands-on activities. *Living with a Star* showed for about five years to about 50,000 people per year.

The *Breathing Space* planetarium show is also a multimedia show. It is geared to grades 4–12 and general audiences on climate change throughout the solar system. The planetarium show explores the effects of the Sun on climate and endemic, external, and human-caused factors that tend to make climates stabilize or change. Teenagers changed the script in order to make it appeal to their peers. Not surprisingly, they added some "gas" jokes. This collaboration with teenagers has helped reach the teenage audience at large. About 100,000 people have seen the *Breathing Space* show. *Breathing Space* was created through several partnerships including PLASTIC E/PO, Plymouth State University, and the New England Science Center Collaborative.

Two space days have been developed at the planetarium in collaboration with the PLASTIC E/PO program, Spacetacular Saturday and Super Stellar Friday. The Spacetacular Saturday is an aerospace festival, part of the national celebration of Astronomy Day. The events during this annual celebration are also possible due to partnerships with the NH Space Grant Consortium, the Plymouth State University, the NH Army National Guard, and aerospace companies. In 2004 and 2005, more than 500 participants enjoyed exhibits, planetarium shows, demonstrations, booths, programs, and activities offered by educators, scientists, and engineers. Figure 6 shows solar telescopes placed outside for the public to observe sunspots and other solar features. The events focused on space science, astronomy, and aviation. The STEREO E/PO team at UNH ensured that items and information provided by NASA STEREO E/PO were distributed. In addition, U.S. Space and Rocket camp scholarships were awarded to youth.

Fig. 6 Solar viewing at Spacetacular Saturday

The Super Stellar Fridays occurred for 50 Friday nights per year for two years. During these nights, STEREO E/PO activities at the Planetarium included a program series geared toward teens, families, and adults. The activities included sky observation, lectures and multimedia shows in the theater, hands-on workshops, immersive activities for families, and a monthly teens-only immersive workshop and show. Common expressions from the teenagers who attended these nights were: "That was awesome, Teen night is awesome!" and "It is a lot of fun to get together with people who know about space and to eat pizza." One scientist who gave a presentation to this teenage night was amazed that they could get so many teens out for this talk and was impressed by their questions, both the quantity and quality. Attendance exceeded 1,200 people per year. The STEREO PLASTIC E/PO led the efforts with the Christa McAuliffe Planetarium.

To reach an even larger audience and one that is national in scope in 2001 and 2006 the Sun–Earth Education Forum (SECEF) worked with the Exploratorium to provide a live web cast of the total solar eclipses in Africa (2001) and in Turkey (2006). STEREO was featured in both of these huge public events, and most of the E/PO teams took part in events around the country. For the 2001 eclipse, the STEREO E/PO team at UCB coordinated video interviews of the STEREO scientists. The scientists spoke about their roles in the STEREO mission and their views of the solar eclipse. The Exploratorium has a web site where these interviews have been woven together with solar science content and footage of the eclipse, accessible from both the Exploratorium and IMPACT E/PO web sites. The IMPACT E/PO web site URL is located in Sect. 4. For the 2006 live web cast of the eclipse on March 29, the Exploratorium interviewed a STEREO scientist representing the STEREO mission about solar storms. Both of these events reached hundreds of thousands of people in science centers around the country, who watched the broadcast of the live web cast. Archived data can be accessed on the web site for later viewing. The 2006 live web cast received excellent coverage in all 50 states and at least 37 countries. MSNBC, which provided simultaneous web cast, had 23,162 unique users, with a record 1,576,624 streams downloaded in one day. The Exploratorium Eclipse web site reported 627,901 unique visitors from March 2006 until June 2006. Thousands of other people participated via museum events, amateur astronomer events, and teacher's lessons in the classroom.

3.2 Musicians, Artists, and Solar Data

The STEREO E/PO group at UCB worked with graduate student musicians, Roberto Morales and David Bithell, at the Center for New Music and Auditory Technologies (CNMAT) to create three software programs that would allow users to listen to data through a process known as sonification. This project was designed to help the public, musicians, and artists engage in the nonvisual STEREO data. One of the programs, called "Incandescence," targets musicians and artists and allows them to creatively explore sound using solar data as a rich generative material. This program uses Helios 1 and 2 solar energetic particle (SEP) events. A second program, called "Stereo Spectro," is designed for science enthusiasts and scientists who want to listen to three-dimensional color graphs of solar particle and radio wave data. This program's interface is shown in Fig. 7. A third program, called "Beginning Application," was created to help students and the public to learn how the data are plotted and pitches are changed according to the value of the data. While working on incandescence, R. Morales composed a symphony called "Turning Point." He included a section in the symphony piece inspired by SEP events, as detected by satellites Helios 1 and 2. The piece was performed in Mexico in 2004. This project inspired several magazine articles in "Seed" and "California Magazine," a radio interview (St. Louis, KMOX Radio 1120 AM), and part of a STEREO exhibit at a science museum (Science Museum in London, UK). The programs and samples of the sounds created by the programs can be found on the IMPACT E/PO web site. IMPACT E/PO led this effort with the STEREO/WAVES (S/WAVES) E/PO, which is also taking part in sonification to help bring alive the "invisible universe" of radio waves.

4 Public Outreach

Through our public outreach efforts, we seek to address the needs of the public such as: "Although Americans express strong support for science and technology (S&T), they are not very well informed about these subjects" and "The Internet is having a major impact on how the public gets information about S&T" (NSB Report 2004). We aimed to share the STEREO science and mission with the public by: (1) creating web pages explaining the STEREO science and mission, (2) providing data such as 3-D images of the Sun to the public, and (3) creating multimedia, paper, and other types of products for dissemination to the public and for use in the media, public events, teacher PD workshops, science centers, and planetariums.

4.1 Reaching the Public via the Internet

The Internet is a incredibly rich resource of information, and almost all of the STEREO E/PO efforts are documented on the web or have web components. The projects and activities described in this paper can be found on the web sites in Table 1. The NASA STEREO web site is the official "portal" and all the web sites in Table 1 can be found through the STEREO web site, even if indirectly. This portal links to the mission and instrument suite web sites, which then link to the education programs associated with the mission and instrument suite websites. The Goddard Space Flight Center web site (STEREO Mission) has links to almost all of the other websites listed in the table. Most of these web sites explain at a public level the scientific background, the spacecraft instrumentation, and data analysis techniques. Many also have grade-level appropriate, hands-on projects that one can do to understand the various instrument, satellite, and project science.

4.1.1 Data Availability to the Public

Space mission data can and has been effectively used in classroom activities and lesson plans (e.g., NASA's Student Observation Network) by museums and science centers. The data can

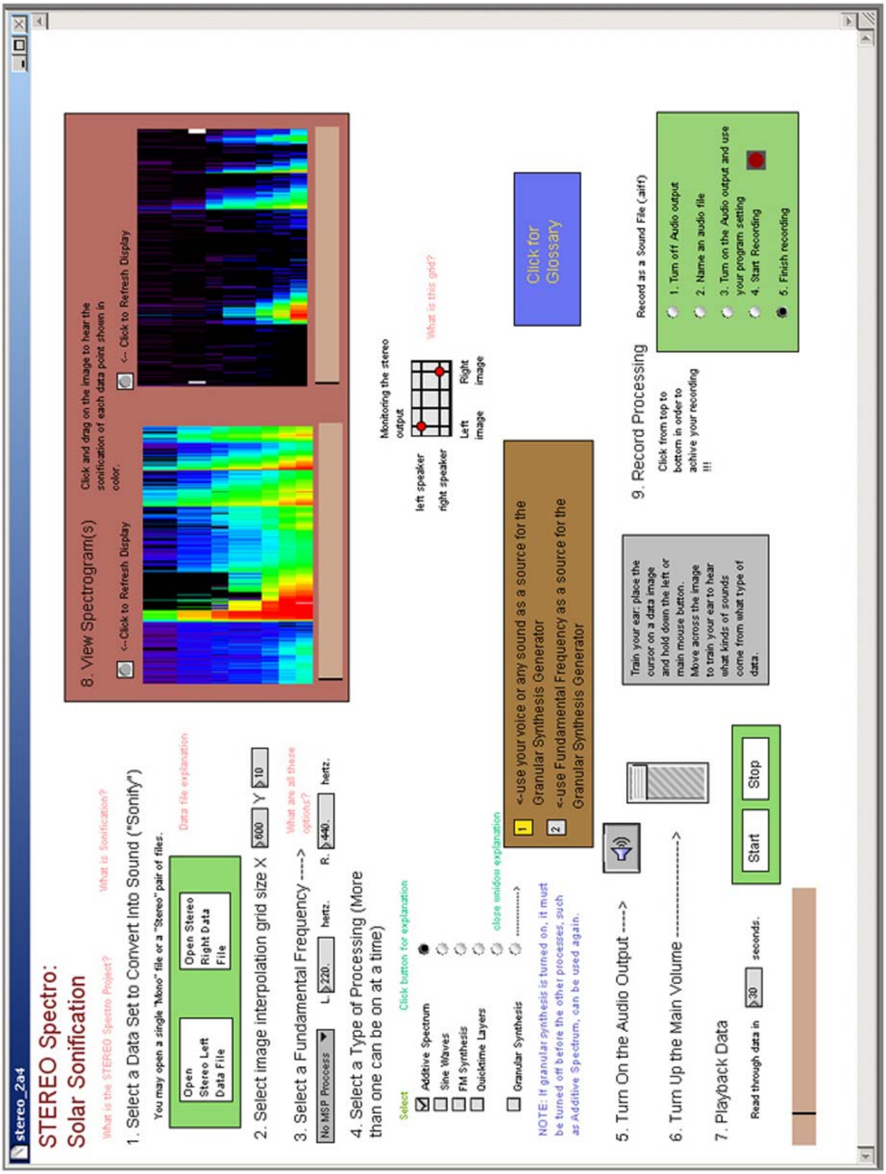

Fig. 7 Interface of the Stereo Spectro software program

Table 1 Relevant STEREO E/PO web sites

Website Name	URL	Brief description and web statistics when available
NASA STEREO	http://www.nasa.gov/stereo/	Information, news and media 556,046 page views for 2006
STEREO Mission	http://stereo.gsfc.nasa.gov/	Public site with educational information 73,779 page views in 2006
IMPACT E/PO	http://cse.ssl.berkeley.edu/impact	E/PO information on magnetism and solar particles 106,007 page views in 2006
Christa McAuliffe Planetarium	http://www.starhop.com/	Information about outreach events (PLASTIC supported)
APL spacecraft E/PO	http://stereo.jhuapl.edu	E/PO information on spacecraft and engineering
STP/LWS	http://stargazer.gsfc.nasa.gov/	The space weather challenge web site

At these web sites, one can find more information about each of the E/PO programs including the products developed by the STEREO E/PO team. Several of the web sites also describe the instrument suites and/or the STEREO mission at an appropriate level for the public.

also be accessed directly by the public. Connection with the data brings the excitement of involvement in a NASA mission to students, teachers, and the pubic in general. Because of the importance of data to the public, STEREO science data are available in public-friendly formats through the STEREO mission web site and through several of the E/PO sites. Along with the STEREO data, the web sites provide the necessary background information and mission details to put everything into context and enable visitors to understand the big picture. For example, the S/WAVES E/PO data will be accompanied by information on the triangulation and tracking of solar radio bursts from flares and CME-driven shocks.

The completely new, three-dimensional (3-D) aspect of SECCHI imagery provides both an opportunity and a major challenge for exploiting the educational potential of the STEREO Mission. 3-D images can be accessed from the NASA STEREO portal and the STEREO mission web sites. The STEREO E/PO program is using the 3-D rendered images to communicate important themes related to the *Benchmarks for Science Literacy* (AAAS 1993) as key ideas that should be understood by all scientifically literate Americans. Examples of such themes are:

- The Sun, with its hot, layered atmosphere and constant evolution of a solar wind that pervades heliospheric space, washing over the Earth and the other planets.
- The constantly changing aspects of the magnetic Sun: 11/22-year sunspot cycle, sunspots, active regions, flares, coronal mass ejections (CMEs), solar storms and geomagnetic storms, and space weather.
- Geomagnetic effects and the rapidly increasing vulnerability of technological systems to solar activity.
- Implications of solar activity and space storms for humans in space and extended space exploration such as the recently adopted Moon–Mars exploration initiative.

Fig. 8 Cover of the APL Mission DVD

STEREO data are available for incorporation into other existing efforts such as the NASA Sun–Earth Viewer and the Student Observation Network, allowing for a much broader dissemination.

4.2 STEREO Products for the Public and General Educational Use

Many different products have been created for the public and general educational use: (1) a CD-ROM with images, media, and other STEREO science and mission content for general educational use; (2) a DVD with a video and also images, media, and other STEREO-related content; (3) a STEREO E/PO poster and a STEREO mission poster; (4) STEREO flyers; (5) educational booklets; (6) satellite cut-outs; (7) a STEREO lenticular; and (8) bookmarks, pins, pens, and decals. Many of the E/PO programs have taken instrument and satellite photographs and placed them on their web sites with appropriate captions. We'll describe several of these products in more detail.

The STEREO mission CD created by the STEREO project office is a comprehensive educational outreach product that helps to explain the STEREO mission and solar science, both to a middle school audiences and to the general public. A primary goal of the CD is to present the information by explaining concepts through simple animations, video, interviews, hands-on demonstrations, and activities as well as articles. This provides easy access to images, media, and other content so that educators can incorporate it into their teaching curriculum or used solely as a resource for students and general users.

In the STEREO project's CD, an example of how the Sun impacts our everyday lives is described and then used to explain the necessity for STEREO's satellite research. Throughout the CD, interactive animations are available to explain STEREO's satellite specifications and its different instruments. The Mission FAQ section features video interviews of members of the STEREO team and allows the user to find answers to questions concerning CMEs, solar science, STEREO, and space research. Hands-on demonstrations have also been video recorded to help teachers, students, and science center personnel in performing the demonstrations. STEREO outreach products and resource material are also provided including a glossary, acronym list, and links to STEREO and Sun related articles.

APL created a DVD with images and mission content as well as video that focus on the unique aspects of designing spacecraft to study the Sun in 3-D. Figure 8 shows the DVD cover. The primary target audience is students and museums/science centers, with the media as a secondary audience. The video addresses the following questions: "Ever wonder why two spacecraft are needed to study the sun or how you build them to operate in the extreme conditions they'll experience in space?" "How do you launch two spacecraft on one

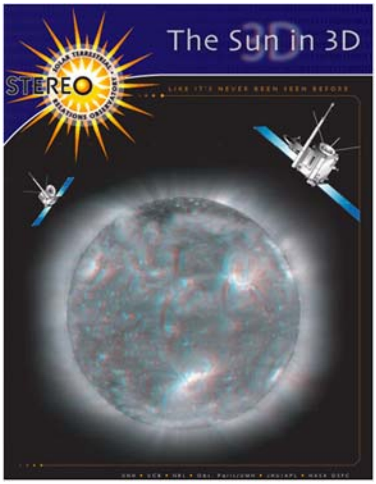

Fig. 9 Front of the STEREO E/PO poster

rocket?” This six-minute video, “Solar News Network: NASA Gets a Double Dose of the Sun,” uses a broadcast news approach to help answer these questions. This project included the production of on-camera interviews, animation, footage of milestone events, ranging from integration and test through launch. On this DVD are also four sets of animations titled: “Preparing for Flight: Closing the Launch Vehicle’s Fairing,” “Placing STEREO into Orbit,” “Twin STEREO Observatories in their Orbits,” and “Seeing with STEREO.” In addition to the DVD and the web site, these animations were used on NASA TV, and as supporting imagery for broadcast media. APL created an educational booklet detailing a behind-the-scenes look at the engineering and technology factors associated with the twin STEREO spacecraft, and the trajectory needed to place them in orbit for their 3-D views of the Sun. This guide complements the DVD by providing a more in-depth overview. It also acts as a stand-alone booklet for general educational use.

The STEREO E/PO 3-D Poster is an educational poster produced by the STEREO project office and intended for a middle- and high-school level audience. The main focal point of the front of the poster is a large red/blue 3-D image of the Sun, to be viewed using the accompanying red/blue 3-D glasses, as shown in Fig. 9. The back of the poster contains a brief overview of the STEREO mission and science to be performed, as well as two activities easily performed in a classroom setting. This poster was evaluated by the NASA education review as excellent and the STEREO team has experienced hundreds if not thousands of “Ahhhh!”s when children see it with the red-blue glasses.

Three distinct flyers were created by the IMPACT, SECCHI, and APL E/PO teams. The IMPACT E/PO flyer describes the IMPACT goals and the E/PO efforts with the Mapping a Magnetic Field activity from the *Exploring Magnetism Teacher’s Guide* discussed in Sect. 2.3. It was evaluated through the NASA space science review and updated with the comments from the review committee. The SECCHI flyer is a brochure on CMEs, how coronagraphs work, EUV disk imagery, a history of coronagraphy and coronal observations, sungrazing comets discovered by space coronagraphs, and how the Sun itself works. The APL flyer is an educational fact sheet, which tells about the two STEREO spacecraft. All of these flyers are available in hard copy and placed on web sites to be downloaded. In addition to the educational community, these handouts serve the media and general public.

APL, SECCHI, and IMPACT E/POs have all worked with photographs and images for general education consumption. APL has managed the collection and captioning of the

STEREO photographs. This collection was separated into the following sections: Assembly and Testing of the Twin Observatories; Shipping the Observatories; Prelaunch Environmental Testing; and Artist Concepts. The IMPACT E/PO team also has a multimedia section with IMPACT photographs available to the public with captions. The SECCHI team has created graphic and narrative presentation of the SECCHI instrument design and operational concepts, and the preparation and test activities necessary to assure full functionality on orbit. SECCHI has also created combinations of graphics and real data presentations to convey the three-dimensional and dynamical nature of CME/storm disturbances as reconstructed from STEREO-A and STEREO-B.

Most of these products can be found on the web sites in Table 1. Besides access via the web sites, these products have been and will continue to be disseminated at: (1) the preservice courses discussed in Sect. 2.1; (2) educational workshops such as NSTA, as discussed in Sect. 2.2; (3) pre- and post-launch activities, for example, a total of 25,000 copies of the IMPACT E/PO flyer were included in the 2005 and 2006 SECEF Sun–Earth Day packets; (4) scientist/engineer guest events for students, as discussed in Sect. 2.4; (5) various other such outreach events, such as the planetarium days discussed in Sect. 3.1; and (6) to other E/PO professionals at conferences such as the American Geophysical Union (AGU). Over 100,000 products in total have been disseminated across the country to students, teachers, and the general public.

5 Conclusions

As described in Sect. 1, there is great need in the United States to help increase the scientific knowledge of students and teachers, to inspire students to become scientists and engineers, and to share with the public information about specific scientific programs. Over four years, the STEREO E/PO program has striven and succeeded in meeting some of the need for physics and space science content knowledge and lessons. Thousands of teachers indicated they would use in their classrooms the information and lessons given at in-depth preservice college courses and in one-hour to two-day long in-service teacher professional development workshops about the Sun and the physics of the Sun. The STEREO E/PO program has taught students directly about space science, being or becoming a scientist or engineer, and the science of the STEREO mission through large student events. And the STEREO E/PO program has aimed to meet the needs of the public for information about current science missions. STEREO E/PO has also excited and inspired teens and the general public through several science center activities, including the Breathing Space Planetarium show in New Hampshire, the Sun–Earth day eclipse web casts shown around the world, and through programs that turn data into sounds.

Because of limited funding for NASA E/PO, it is vital to work with partners who can help leverage small programs to increase their impact, to sustain programs, and to disseminate materials. The STEREO E/PO program has done this and more with each of its programs. Most of the programs described here have a diversity of partnerships. For example, the preservice teacher program leverages from a collaboration between the departments of Education and Physics at the Catholic University of America, NRL, and the NASA Goddard Space Flight Center. The in-service teacher PD workshops leverage SECEF and several other NASA mission E/PO programs. The printing of the magnetism teacher guides was also leveraged from other NASA mission E/PO programs. The science center education programs would not be possible without the partnership of the NH Christa McAuliffe Planetarium and the annual Sun-Earth Day put on by SECEF. Partnering with musicians created an interesting product for the sonification project. All of these partners have put in-kind work and brought their unique expertise, which the STEREO E/PO program needed to succeed. Most of these partnerships will work to ensure that these programs continue long after the STEREO E/PO funding is gone. The partnership with Sun-Earth Day and other NASA E/PO programs have helped to share the STEREO mission and its science and disseminate the STEREO E/PO products with thousands of members of the public and teachers around the country.

One of the benefits of E/PO programs from NASA is the inspiring content and the contact with working scientists and engineers. The STEREO E/PO program is made much more effective because all of the Principal Investigators associated with the suite of instruments are deeply committed to E/PO and have played an active role in the programs. In addition, the education specialists who work with these programs are scientists themselves, and are able to bridge the gap between the science world and the education world. All of the programs have directly involved a scientist working with the STEREO E/PO program. And all of the programs have been developed around the STEREO science content of the dynamic sun. The many products that have been created for the STEREO E/PO program all contribute toward explaining the science of the Sun and the STEREO mission.

Because the United States is so diverse in population, it is crucial to try and reach all types of people through E/PO programs. The STEREO E/PO program has emphasized women scientist role models and mentors. It has also worked with many teachers who teach mostly Hispanic and African American students. In these ways, this program tries to reach out to those not typically represented in the science community—especially in space science.

To really discover if STEREO E/PO has made long-term changes in people's knowledge and attitude about science, the Sun, and careers in science, would take more funding than is typically available through NASA E/PO programs. However, some of the STEREO E/PO program elements were evaluated to determine how useful they were to their audience. These formative evaluations were used to guide the program's development, such as the planetarium shows and the teacher classes and workshops. A couple of the programs had summative evaluations, such as the NASA-reviewed teacher guides and poster. Most programs used internal evaluation to produce their own questionnaires, collect data, and act on these data. An outside evaluator, Cornerstone Associates Inc., LCC, was leveraged from another NASA E/PO program to help evaluate several of the in-service teacher PD workshops. The STEREO E/PO program evaluations have shown that the STEREO E/PO program is educating teachers in a meaningful way, producing classroom materials which will be and are being used in the classroom, providing exciting events for students, and reaching many people across the country, mostly on the East and West coasts. We have also learned some of the challenges teachers face in using our materials (such as not having the funding resources to obtain magnets and compasses for the classroom). However, no outside evaluator has considered the discrete elements as a whole program, therefore there are no STEREO E/PO evaluation reports. Furthermore not all the elements in the overall program have been evaluated. Future E/PO programs, including the ongoing STEREO E/PO program, should plan for a well-defined evaluation strategy with a single outside evaluator looking at the impact of the entire program. The evaluator should be included at the beginning of each program to determine what type of overall impact the program has had.

Perhaps the biggest challenge of the STEREO E/PO team experienced was coordinating and sharing each other's projects and materials, with the exception of the more public outreach materials such as the STEREO poster. The STEREO E/PO program is incredibly diverse with a number of different people working on different programs. Each team (the four instrument teams, the spacecraft bus team, and the management team) developed their own programs separately. In 2004, Dr. Kucera was appointed to coordinate the groups, and this paper is one result of this organization. A benefit of having so many different people involved is that the STEREO E/PO prelaunch program as a whole has been diverse and national. However, one of the lessons learned regarding E/PO of large NASA space science missions is that it is imperative to the cohesiveness of the E/PO programs to have an E/PO lead overseeing the E/PO programs from the beginning of the mission planning.

The STEREO E/PO program will continue after the STEREO satellites are in space. In addition to the continuation of the teacher classes and workshops, the sustained efforts will focus on dissemination and evaluation of the E/PO products, programs, and including STEREO data in the E/PO activities. The STEREO data will be shared with the public both as solar images, as described in Sect. 4.1.1, and as sound, as described in Sect. 3.2. Through this continued effort, we hope to share with students, teachers, and the public, the many exciting discoveries we expect from the STEREO science mission. And we hope to find out if this program, as we believe, has had an overall positive impact on students, teachers, and the general public.

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