GA–A28117

ADVANCING PRECOLLEGE SCIENCE AND MATHEMATICS EDUCATION

FINAL REPORT

by
PROJECT STAFF

DATE PUBLISHED: MAY 2015

GENERAL ATOMICS

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ABSTRACT

With support from the US Department of Energy, Office of Science, Fusion Energy Sciences, and General Atomics, an educational and outreach program primarily for grades G6-G13 was developed using the basic science of plasma and fusion as the content foundation. The program period was 1994 - 2015 and provided many students and teachers unique experiences such as a visit to the DIII-D National Fusion Facility to tour the nation's premiere tokamak facility or to interact with interesting and informative demonstration equipment and have the opportunity to increase their understanding of a wide range of scientific content, including states of matter, the electromagnetic spectrum, radiation & radioactivity, and much more. Engaging activities were developed for classroom-size audiences, many made by teachers in Build-it Day workshops. Scientist and engineer team members visited classrooms, participated in science expositions, held workshops, produced informational handouts in paper, video, online, and gaming-CD format. Participants could interact with team members from different institutions and countries and gain a wider view of the world of science and engineering educational and career possibilities. In addition, multiple science stage shows were presented to audiences of up to 700 persons in a formal theatre setting over a several day period at Science & Technology Education Partnership (STEP) Conferences. Annually repeated participation by team members in various classroom and public venue events allowed for the development of excellent interactive skills when working with students, teachers, and educational administrative staff members. We believe this program has had a positive impact in science understanding and the role of the Department of Energy in fusion research on thousands of students, teachers, and members of the general public through various interactive venues.

1. INTRODUCTION

The Energy/Fusion Group at General Atomics (GA) is pleased to submit this final report for educational and outreach-based grants that began in 1994 and continued until May, 2015. The grants' support has allowed scientists and engineers working at GA to develop an extensive array of plasma and fusion science-based hands-on activities that have met or exceeded the experiential expectations of teachers, students, and the general public in venues that included in-house tours, local expositions, workshops, and science stage presentations included content areas that supplemented pre-college level science curricula. The main audience for this work was middle school and high school students and their teachers. Additional audience members included undergraduate students, the general public, and, in the case of the Distinguished Lecturer Program, graduate students and university faculty. The support has allowed thousands of students and hundreds of teachers from more than a dozen states to interact with professional scientists and engineers and learn about the fascinating science of plasma and the technology required to bring Earth-based fusion energy production into the future of humanity. We appreciate the many years of support from the DOE/OFES for this important work and feel that persons who have participated in this program have been positively influenced in their thinking of science as a profession or a socially supportable endeavor. Many of the participating teachers indicated they developed a deeper understanding of the science, technology, and challenges of fusion on earth.

This report will highlight key efforts made in developing and maintaining an outreach program primarily for grades G6-G13 by professional scientists and engineers from within the

fusion-science field, but with varied institutional origins working closely with educators to define grade-appropriate content and demonstrations. To insure conciseness, cumulative results will be presented in tabular form rather than following a written historical account of project growth, even though this report covers a grant period of approximately 20 years. However, limited historical perspectives will be included as needed for clarity.

2. KEY DEVELOPMENTS OF THE GA FUSION EDUCATION PROGRAM

2.1. Reaching out: from paper to digital media

A major strength of the education/outreach program at General Atomics has been its ability to grow and mature using input from teachers, school administrators, and students. Early aspects of the program, beginning in 1993 with GA support and later in 1994 with DOE support, were limited to paper-based handouts, 35-mm slide presentations, and DIII-D Facility tours but matured as productive discussions between teachers and presenters occurred. Master demonstration kits for loan to schools were made and included content covering the electromagnetic spectrum and radioactivity. During the successive years, the program expanded to include additional formats of interaction including off-site visits to classrooms (Scientist-in the Classroom, or SiC), county-wide science expositions (San Diego High Tech Fair, San Diego Festival of Science, Space Day, and Padres Science Field-trip Day), nation-wide interactions (APS/DPP Teachers Day and Student Plasma Expo), and Science & Technology Education Partnership (STEP) events in California and Hawai`i. An educational video, "Fusion, Nature's Fundamental Energy Source," and an interactive CD, "STARPOWER," were produced and distributed. Additional formats included a teacher workbook, an internet website, and posters in multiple languages. Table 1 provides a description of the informational hand-outs that were sent to many thousands of teachers and students around the world.

TABLE 1. EDUCATIONAL MATERIALS FREELY DISTRIBUTED WITHIN PROJECT PERIOD OF 1994 - 2015

	Description
Teacher Notebook: Curriculum modules	Large 3-ring binder with several modules and a workbook
Electromagnetic spectrum	Text and activities; Paper; PDF on website
Radiation and Radioactivity	Text and activities; Paper; PDF on website
Fusion workbook	Text and quizzes; Paper; PDF on website
Posters	
Electromagnetic Spectrum	Colorful classroom poster with spectrum science; Multi-color paper; PDF on website
Radiation & Radioactivity	Colorful classroom poster with radiation science; Multi-color paper; PDF on website
Fusion	Colorful classroom poster; multi-color paper; PDF on website
Data Acquisition	Colorful classroom poster with computer information; Multi-color paper; PDF on website
Design & Engineering	Colorful classroom poster with emphasis on graphite tile design; Multi-

	color paper; PDF on website
Videotape/CD-based	
STARPOWER	Highly interactive gaming CD with puzzles and a fusion power plant based on real-world physics.
"Fusion – Nature's Fundamental Energy Source"	Introduction to laboratory fusion science. Videotape, CD formats.

2.2. Activity & event design and implementation includes many facets

The GA Education and Outreach (E&O) Program provided many opportunities for participants to interact with equipment or each other as well as avenues to explore on their own. These opportunities included participation in events held at the DIII-D Facility, various schools, public areas, and hotels/convention centers. Aside from GA personnel involvement, E&O Program team members were from various institutions (Princeton Plasma Physics Laboratory (PPPL), Lawrence Livermore National Laboratory (LLNL), Columbia University (Columbia U), University of California Berkley (UCB), plus others) and helped in designing demonstrations, authoring materials, being tour guides, hosting workshops, and staffing booths at student expo events. Program events, whether interactive or passive in nature, incorporated learning-based characteristics relevant to teachers and students including grade-appropriate content and execution of demonstrations in an understandable fashion. The design of activities to be used during the events included a purposeful degree of complexity, flexibility, and longevity. Table 2 is a compilation of the primary events undertaken within the program and includes their venue, associated activities, intended audience, and anticipated outcomes.

TABLE 2. GA ENERGY/FUSION E&O PROGRAM ACTIVITY SUMMARY				
Event	**Venue**	**Major Activities**	**Primary Audience**	**Anticipated Outcome**
DIII-D Facility tours	DIII-D Nat'l Fusion Facility, San Diego, CA	Interactive stations covering multiple topics in plasma/fusion science	G5-G13 students	Foster awareness of research-based STEM areas & DOE research
Science & Technology Education Partnership (STEP) Conference	Bourns, Inc. Riverside, CA Honolulu, HI Lihue, HI	Science stage shows, interactive booth	G4 - G9 students	Excite students about an array of STEM disciplines; provide teacher workshops when available
San Diego High Tech Fair	San Diego/Del Mar Fairgrounds	Interactive booth covering plasma, electricity & magnetism	G4 - G12 students	Inform students about an array of STEM disciplines and DOE research
Long Night of Art & Innovation	Riverside, CA. Outdoor evening event	Interactive booth covering plasma, electricity & magnetism	General public	Excite the public about STEM disciplines & DOE research
San Diego Festival of Science & Eng.	Petco Park, San Diego	Interactive booth, brief stage presentations	General public	Excite the public about STEM disciplines & DOE research
Space Day	San Diego Air & Space Museum	Interactive booth covering plasma, electricity & magnetism	General public	Excite the public about STEM disciplines & DOE research
Scientist in the Classroom	School classrooms	Demonstrations on states of matter, E&M, and the electromagnetic spectrum	G5-G13	Demonstrate scientific principles using easily understandable activities
Teacher workshops	APS/DPP national mtg. sites; GA, NSTA, CSTA mtg. sites	Workshops on plasma & fusion based science	Science educators	Empower teachers with classroom demonstrations for their students
Teacher Build-it Day workshops	GA, STEP venues	Single and multiple day workshops emphasizing demo construction by teachers for their classroom	Science teachers and educators	These 'build-it day' projects increased a teacher's ownership and confidence in the device.

3. INTERACTIVE DEVICES OFFERED CLEAR DEMONSTRATION OF CONCEPTS

GA Fusion Education & Outreach program personnel developed more than 20 interactive demonstration devices covering the basic concepts central to fusion science and relevant to today's student population. Each interactive device was designed to highlight specific concepts and allow the participant to clearly observe the phenomenon being presented. A primary goal of the demonstration device was to present science & engineering in a transparent fashion to students without having concepts hidden in a 'black box'. Table 3 lists the interactive devices we developed to illustrate various scientific principles and to address specific education standards. In addition, the table lists whether a particular interactive device would be suitable for teachers to build in a 'Build-it Day" workshop venue as briefly introduced in Table 2.

TABLE 3. SUMMARY OF INTERACTIVE DEVICES USED IN VARIOUS VENUES

Scientific Principle to be Illustrated	State or National Standard Addressed	Demonstration Device	Suitable for Build-It Day Workshop?
Differential pressure	Concepts of origin of air pressure	4 in. vacuum chamber with hand pump	Yes
Differential pressure and science history	Concepts of origin of air pressure	5 in. flat plates with hand pump ala "Madeburg Spheres"	Yes
Magnetic field produced via current in coil	Moving charges make a magnetic field	200-turn and 400-turn 12 in. diameter coils	Yes
Electric field produced by a changing magnetic field	Changing magnetic field produces an EMF	600 turn (very fine) coil with LED	Yes
A. Eddy current produces a friction-like force	Changing magnetic field induces current which produces magnetic field	Parallel copper sheets with small cylindrical magnet	Yes
B. Eddy current produces a friction-like force	Changing magnetic field induces current which produces magnetic field	18 in. long, thick-walled copper pipe and spherical magnet	Yes
C. Eddy current producing a repelling force	Changing magnetic field induces current which produces magnetic field	200 turn electromagnet, 120 Vac, 24 in. x 24 in. x 0.125 in. Al sheet	Yes
D. Eddy current producing a repelling force	Lenz' Law	Commercial can launcher and crusher	Not using present device

TABLE 3. SUMMARY OF INTERACTIVE DEVICES USED IN VARIOUS VENUES			
Liquid to gas phase change	States of matter; phase changes	Allow liquid nitrogen to warm and expand into a latex glove; observe, predict (based on experience), carry out the experiment, conclude	Partly; teacher (generally) has little access to liquid nitrogen but can sub dry ice
Liquid to solid phase change	States of matter; phase changes; safety	"Freeze" hot dog in liquid nitrogen in plastic sandwich bag	No, teacher (generally) has limited access to liquid nitrogen
Relationship between temperature, pressure, and volume of gas	Boyles' and Charles' laws	Place sealed inflated balloon into liquid nitrogen bath. Observe reduction in balloon's size.	Not when using N_2. Can be approximated with balloon in home freezer
A. Plasma state of matter	Plasma as the fourth state of matter; gas to plasma change	Half-coated fluorescent tube; Tesla coil, interactive plasma devices	Yes
B. Plasma state of matter (equil mix of ground state, excited, and ionized gas)	Plasma as the fourth state of matter; equil mix of ground state, excited, and ionized gas	Germicidal tube, 300 Vdc PS	Yes
C. Plasma charac. as a function of changing pressure	Plasma as a state of matter; effects due to changing air pressure	Plasma device 3 – a variable pressure 18 in. x 6 in. diam. (plastic tube) air plasma device with HV supply and 120 Vac vacuum pump	Yes
D. Plasma conductivity in atmosphere	Lightning as plasma example on earth	Hand held Tesla coil (30kV) Large Tesla coil (500kV)	Yes: 30kV coil
Magnetic field and plasma interactions	Magnetic field influence on trajectory of charged particles	Glass envelop; Ne or Ar gas, HV supply, hand-held magnet; Helmholtz pair and e-gun	Maybe
Spectroscopic charac. of a plasma due to excitation levels	Origin of light; electron energies in atoms & molecules; spectroscopy	Diffraction grating, Ocean Optics USB spectrometer; Geissler tubes	With gratings, yes; less likely with OOS
Simple model of atom	Atomic structure	Styrofoam balls and rubber bands	Easily made by teachers outside of workshop
Transmission/absorption of electromagnetic energy	Energy as transverse waves; non-ionizing radiation	Radio and Faraday cage, microwave oven door; flashlight and opaque glasses; IR camera and different thicknesses of plastic; UV source, fluorescent rocks, and plastic sheet	Partially; IR camera not readily accessible to teachers, yet

TABLE 3. SUMMARY OF INTERACTIVE DEVICES USED IN VARIOUS VENUES			
Radioactivity	Radiation, radioactivity; ionizing radiation, shielding	Cloud chamber and radiation sources	Yes
Fusion	Fusion as a natural process for element and energy production	Velcro covered tennis balls; animated PowerPoint® presentation; discussion of periodic table	Easily made by teachers outside of workshop
Wave model	Energy moving as waves in space	Surgical tubing, hand motion, reciprocating saw	Yes
Electromagnetic wave; Poynting vector construction	Energy moving as waves in space	Pencil, paper strips representing E,B field envelopes	Yes
Measure temperature of a plasma (advanced)	Example of physics measurement tool: Langmuir probe	Linear vacuum tube, low voltage diagnostic supply, insertable probes	No
Plasma breakdown dependence on pressure and electrode spacing (Paschen curve, advanced)	Example of physics measurement tool: variable P, d plasma device	Linear vacuum tube variable P, d, gas species device	No

4. TEACHER WORKSHOPS

Half-day, multi-day, and Build-it Day style workshops for teachers were offered by E & O Program personnel. Venues for the workshops included General Atomics and various schools or other venues associated with local, state, or national educational events. Promoting content-rich information to workshop attendees was a primary goal for these workshops and reflected the fact that many teachers tasked with teaching physical science are not necessarily experts in the field. Some of the workshops incorporated a construction component in which the teachers could build a lasting piece of equipment for use in their classroom. The workshops seemed very useful in removing misconceptions about science that teachers sometimes brought with them. Suggestions for using the information in class were offered and teachers were encouraged to discuss how they could incorporate the information into their schedule. Table 4 lists the workshop venues, types, and estimated attendance levels for workshops we've hosted throughout the entire period of performance.

TABLE 4. TEACHER WORKSHOP VENUES AND TOPICS			
Venue(s)	Topic(s) of presentation	Approximate No. of workshops	Estimated No. of attendees
Science Teacher Day, APS/DPP mtg. sites. 1996 - 2014[1]	Plasma science, fusion technology, radiation & radioactivity, the electromagnetic spectrum, nuclear fusion, laser science	54	1080
General Atomics – Build-it Day	States of matter, electricity & magnetism	24	360
Science & Technology Education Partnership Conferences (CA, HI)	Electromagnetism, states of matter, coil making, science of the stage show	9	100
Murdock Foundation Teachers at GA	Plasma, Electromagnetic spectrum, DIII-D Facility tour	12	200
Cal. Science Teachers Association, National Science Teachers Association	Magnetic coil modeling using Excel, plasma and fusion science, the electromagnetic spectrum	3	60

5. SCIENCE EXPOSITIONS FOR STUDENTS AND CLASSROOM PRESENTATIONS

Interactions among scientists (engineers) and students are critical when attempting to broaden students' perspectives about choosing a career. These interactions may also allow for concept reinforcement to occur by the student outside of the usual classroom venue with student and teacher. Scientists, engineers, and technicians from the GA Fusion E&O team participated in student and public interactions through classroom visits and local & national science expositions. The topics of the presentations were typically plasma science, fusion technology, radiation & radioactivity, the electromagnetic spectrum, nuclear fusion, and electricity & magnetism. Table 5 lists the venues and estimates of associated participation for expo-style and classroom venues. It is important to note the repetitive nature of the GA E&O Team's appearances at SiC and science exposition events. While many events are held once a year, in most cases, organizers and teachers were eager to have us participate every time.

[1] We did not participate in 2013 DPP mtg

TABLE 5. INTERACTIVE STUDENT-BASED SCIENCE EXPOSITIONS[2] AND SCIENTIST IN THE CLASSROOM (SIC) PRESENTATIONS		
Venue(s)	Approx. No. of invited appearances	Estimated No. of attendees at event (cumulative)
Plasma Expo, APS/DPP mtg. sites. 1996 - 2014[3]	13	30,000
San Diego High Tech Fair (1998 - 2014)	16	50,000
Long Night of Art & Innovation/Orange Festival; public events at Riverside, CA (2012 – 2013)	2	10,000+
San Diego Festival of Science & Eng. (2009 - 2014)	7	350,000+
Space Day (2007 - 2014)	8	3,000
Padres Science Day	2	3,000
Scientist in the Classroom SiC (1997 - 2014)	>225	>28,000
Science stage presentations Science & Technology Education Partnership Conferences (STEP, CA, HI) (CA: 2000 - 2014) (HI: 2004 - 2014)	100	40,000

6. GA E&O TEAM MEMBERS CAME FROM MANY INSTITUTIONS

Personnel involved with the events and activities of the GA E&O program were scientists, engineers, and technicians from organizations across the nation. Team members also worked with professional organizations, such as the San Diego County Office of Education, the San Diego Science Alliance, APS/DPP leadership, and the Kaua`i Economic Development Board and Honolulu School District Supervisors to provide new and exciting venues for educational activities. Table 6 lists the primary team member's and professional associate's home institutions and their major contributions to the E&O program.

[2] Interactive booths were provided by educational, private, and governmental entities

[3] No student expos at the following DPP mtgs: Quebec City (2000), Philadelphia (2006), or Denver (2013)

TABLE 6. GA E&O PROGRAM TEAM MEMBERS AND CLOSE ASSOCIATES CAME FROM A VARIETY OF INSTITUTIONS		
Institution	**Team Member Major E&O Program Contributions**	**Educational, Governmental, or Community Associate Involvement**
Columbia Univ., NY	Provided tour guide and booth staffing	
General Atomics	Tour, workshop, booth hosts; oversaw program execution; provided material development & science stage shows	
LLNL	Provided tour and workshop hosts	
ORNL (ORAU)	Assisted with DPP workshop planning & execution	
PPPL	Tour, workshop, booth hosts; provided material development & science stage shows	
UCB	Assisted with materials development	
UCSD	Assisted with materials development and provided DPP Expo booth staff	
University of Toronto	Tour, workshop, booth hosts; provided material development & science shows	
San Diego County Office of Education & San Diego Science Alliance		Provided opportunities with SD High Tech Fair, local workshops
APS/DPP Leadership		Provided opportunities within the Teachers Day and Student Plasma Expo events at annual meetings
Kaua`i Economic Development board and Honolulu School District Leadership		Invited members to provide science presentations and booths at Kaua`i in STEP and O`ahu in STEP Conferences.
Riverside County Office of Education & STEP organization		Invited the E&O Team to help make and implement STEP at Riverside, CA. We provided science presentations and staff booths at Riverside, CA.

7. AWARDS

Recognition of GA E&O activities include awards from teachers and engineering groups, as well as a citation read into the Congressional Record. Significant recognition and awards earned by team members or activities:

- California Teachers Association, *CTA State Gold Award*, 1997
- The Engineering Societies of San Diego, *Outstanding Service Award* 1998

- Greater San Diego Science & Engineering Fair, *Certificate of Appreciation* Congressional Record, Proceedings and Debate of the 108th Congress, 2nd Session, Vol 152, No. 58, October 8, 2004, *"Tribute to General Atomics"*
- Physics Education, *"Excellent"* rating of the gaming CD, STARPOWER, US DOE. http://iopscience.iop.org/0031-9120/36/2/403/pdf/0031-9120_36_2_403.pdf

8. CONCLUSIONS

The General Atomics Education and Outreach program, with support from DOE/OFES and General Atomics, provided an interesting and unique set of opportunities for many students and educators, both local to San Diego and in many nationwide regions. Helping teachers, students, and the general public to better understand the science of plasma and fusion related fields as well as promoting the Department of Energy's role in supporting science and engineering projects in the quest for earth-based fusion were the key roles of the program. Removing misconceptions about science principles often taught in the classroom also played a critical role in the program. Evidence of the perceived positive educational merit in the program was found in the repeated requests by many teachers for annual participation in SiC and DIII-D Facility tour events. Repeat invitations by outreach organizers (outside the classroom) for GA E&O Team members to return and participate in the STEP Conferences, the San Diego High Tech Fair, and the San Diego Festival of Science and Engineering, among other venues, are indicative of the perceived importance of the team's presentations and their ability to effectively interact with people of all ages. The team members' varied backgrounds and home institutions brought a set of diverse learning approaches to the program and provided students with a broadened view of the world regarding future opportunities for careers in science and engineering. The flexibility of the program allowed for growth in several informational distribution areas including replacing 35-mm slide technology with videotape and complementing paper-based handouts with online formats. Student interest in gaming led to the making of a highly rated game-based CD using real physics principles to support the content while the user pursued training modules in power plant building and the operation of a tokamak-based power plant in the year 2020. The scope and breadth of the activities developed for tour, classroom, and workshop uses allowed for a large number of demonstration combinations to be presented to various audiences. The combination of the development of many interesting demonstration devices, willingness of team members to try new avenues of interaction, as well as the program's maturity over many years, has fostered excitement and a better understanding of science in many thousands of students and hundreds of teachers across the nation.