The LSC White Paper on Education and Public Outreach

Goals, Status and Plans, Priorities (2015-2016)

EPO group of the LSC[1]

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[1]EPO E-mail: lsc-epo@ligo.org, EPO Wiki: http://wiki.ligo.org/EPO, and EPO White Paper Internal Version in DCC: https://dcc.ligo.org/LIGO-T1500291

1 Synopsis

This review outlines the priorities for the Education and Public Outreach (EPO) committee. It also provides a description and summary of efforts and elaborates on the goals, philosophy, and plans of our international network of scientists. It is not meant to be a comprehensive list or to contain the history of all LSC EPO efforts. This is a living document that is updated frequently and is improved continuously.

More than half of the research groups in the LIGO Scientific Collaboration (LSC) are actively involved in projects related to Education and Public Outreach (EPO). The main goal of the broader EPO team is to build on the excitement of LIGO's discoveries to engage the wider public beyond GW scientists, motivating students and increasing the scientific literacy of the general public.

Our motivations include the desire to:

- Arouse interest, attention, and motivation for outreach activities;
- Ensure that collaboration skills are optimally used to enhance the collaboration's public visibility;
- Coordinate the EPO activities of the LSC;
- Streamline and optimize the development and use of EPO resources;
- Create, facilitate, and nourish synergies among teams within and outside of the LSC;
- Interface EPO needs, goals, and objectives to the practical realities (e.g., prioritization, resource management, external hooks, etc.).

The EPO Committee is defined in the Bylaws of the LSC as:

"...
7.13 Education and Public Outreach Committee
7.13.1 The Education and Public Outreach (EPO) Committee is responsible for overseeing and documenting the Collaboration's activities in education and public outreach. The EPO committee is also responsible for formulating the Collaboration's strategic plans to harness the excitement and enthusiasm generated by gravitational wave research in order to inspire and educate students and the general public in astronomy and fundamental science, and thus to help improve science literacy and education among the citizenry.
7.13.2 The EPO Committee consists of a chair appointed by the LSC Spokesperson, and at least four additional members from the LSC (including members from LIGO Observatories) with a spread of interests and expertise in formal and informal education, media relations, and in public and professional outreach.
7.13.3 The chair of the EPO Committee is appointed by the LSC Spokesperson for a term of two

years. Other members of the EPO committee are appointed by the EPO chair for the term of her/his tenure in consultation with the LSC Spokesperson.
7.13.4 The EPO Committee is also responsible for preparing and maintaining a White Paper relevant to the Collaboration's plans and activities for education and public outreach, with an up-to-date version to be available before the beginning of the annual LSC MOU review cycle.
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2 Introduction

The goal of the LSC is the detection of gravitational waves from cataclysmic astrophysical sources. Direct measurement of gravitational waves will open up a revolutionary new window on the Universe, which will probe some of the most violent and energetic phenomena in the cosmos - from black holes and supernovae to the Big Bang itself.

As a frontier physics effort, a core mission of the LSC is to harness the excitement and enthusiasm generated by gravitational wave research to inspire and educate students and the general public in astronomy and fundamental science, thus raising standards of science literacy and education. LSC researchers and students believe that the opportunity to discover the beauty of the cosmos should not be limited by age, culture or abode. The LSC EPO working group aims to communicate the vision and benefits of gravitational wave detection to the public at large throughout the world. By combining different ideas and approaches across participating institutions, the LSC EPO network is able to create outreach programs which are far more effective than they would be if LSC member institutions worked independently. The outreach goals of the LSC include:

- Communicating the scientific activities and discoveries of the collaboration through national and international news media, as the emerging field of gravitational-wave astronomy enters the detection era;
- Improving science literacy in the general population;
- Increasing participation in science, especially among under-represented and underserved groups;
- Helping to reduce existing disparities in the access to educational resources;
- Advocating the intellectual and social / socio-economic benefits of careers in science;
- Recruiting future generations of scientists and engineers, to our own collaboration and to the wider scientific community;
- Providing and coordinating resources for the design and delivery of outreach and education activities by others within the collaboration;
- Improving understanding by the citizenry of frontier science and large scientific projects.

LSC outreach initiatives aim to inform the public not only about the science of gravitational waves and the activities of LIGO and other partner detectors, but also about science in general. LIGO outreach introduces non-scientists to multi-messenger astronomy, high-energy physics, cosmology, laser technology, material science, computing facilities and data acquisition. The cornerstones of this program are:

- The scientific endeavor of the LSC is motivated by the same desire for exploration, curiosity about the unknown and awe of nature that have inspired and motivated humankind throughout millennia of history.

- A new view of the distant Universe will be studied by non-electromagnetic means through the detection of gravitational waves. Mapping the gravitational-wave sky will provide an understanding of the Universe in a way that electromagnetic observations cannot. As a new field of astrophysics it is quite likely that gravitational wave observations will uncover new classes of sources not anticipated in our current thinking.

- Giant, new non-conventional "telescopes" are needed to detect the gravitational-wave spectrum. The cutting-edge technology of these telescopes, called interferometers, is pushing back the frontiers of many scientific fields. A remarkable combination of technological innovations in vacuum technology, precision lasers, measuring techniques, and advanced optical and mechanical systems is required to observe gravitational waves.

LSC outreach programs use different ways to communicate these concepts to the public in formal and informal settings:

- Events at the observatory outreach centers, on-site tours and visits;
- Public events and lectures, projects in local communities;
- Development of printed materials, hand-outs;
- Development of internet-based activities, games, multimedia;
- Use of new social media, Twitter, Facebook;
- Formal education projects, classroom lessons, curriculum development;
- After-school programs, classroom visits;
- Professional development of teachers, graduate students and post-docs;
- Interdisciplinary activities, science and art events;,
- Diversity programs;
- Participation at conferences, science fairs, and exhibits.

These programs offer great potential for public education and outreach at all levels and external funding is continuously sought to realize them.

Target audiences for these activities are school-age children and their families, college students, young adults, teachers and science professionals, and more generally "informal learners", who may have some general awareness of astronomy and its long and rich cultural heritage. Increasing the awareness of current scientific research in the youngest segments of the citizenry is particularly important to achieve the four goals of the "Rising Above the Gathering Storm" report:

- Increase the talent pool in all the participating nations by improving science education;
- Strengthen the participating nations' commitment to fundamental research;

- Educate, recruit, and retain top students and scientists;
- Ensure the leading role of the participating nations in innovation and scientific research.

Acknowledging that this audience is traditionally a difficult one to attract, LSC outreach efforts continuously explore new opportunities to promote science among adolescents and young people.

LSC outreach programs also contribute to human resource development in science by providing opportunities for the mentoring of post-docs, graduate and undergraduate students in the field of gravitational physics and science in general. An important component of LSC outreach programs is training students to become the next generation of science educators. Through participation in outreach projects, junior researchers and students have the opportunity to engage with the public and improve their teaching and communication skills.

3 Education and Public Outreach of the LIGO Laboratory

LIGO Laboratory began implementing public outreach programs at Livingston and Hanford after the completion of construction in 1998. The sites provided tours of the facilities and summer teacher internships from the outset as the Observatory Heads built relationships with nearby institutions and outreach interests. After years of steady growth in the breadth of outreach activities and in the strength of regional partnerships, LIGO's site-based programs reached nearly 25,000 people in 2014. Each observatory aims to thoughtfully serve the large underrepresented populations that reside in the nearby counties/parishes. LIGO Livingston's Science Education Center (SEC) now represents a premier science education destination in the Louisiana region, offering dozens of compelling hands-on physics exhibits and hosting a growing variety of innovative science programs for students, teachers and the general public.

3.1 Overview

Staff (4.25 FTE) are responsible for operating the outreach programs at the observatories. Numerous members of the site technical staffs and LSC technical visitors also participate in site-based outreach activities. The Hanford and Livingston outreach teams coordinate the outreach involvement of these individuals. The vast majority of Hanford and Livingston outreach contacts are face-to-face. Additional site-based interactions occur with visitors who connect to the observatories via Skype and similar virtual platforms.The LSC-EPO Working Group provides a mechanism for Lab personnel to participate in national and international gravitational wave outreach projects. The Lab outreach team brings resources from the observatories to bear on these projects as needed. Technical and outreach staff in the Lab collaborate with members of LSC-EPO in promoting LIGO to the public and to diverse student groups through participation in conferences and exhibitions. Activity also flows into the Lab through LSC-EPO as personnel at LSC locations are able to connect their local constituents with education resources that are available through the observatories.

3.2 LIGO Livingston Observatory and the LIGO Science Education Center

3.2.1 Past and Current Activities

In 2004, a successful proposal to the NSF authored by a partnership of LIGO, Southern University at Baton Rouge (SUBR), the Exploratorium, and the Louisiana Systemic Initiative Program and Louisiana GEAR UP resulted in the construction of the 10,000 sq. ft. Science Education Center

(SEC) at the Livingston site. The SEC currently houses over 50 Exploratorium-style exhibits that focus on the science themes of LIGO. Auditorium and classroom space near the exhibit hall amplify the educational value of the facility, allowing the staff to delve into topics in more depth. Three LLO outreach staff members operate the SEC with assistance from undergraduate SUBR docents and LLO staff. The Exploratorium continues to partner with the SEC on exhibit training and teacher professional development. The SEC has become a key destination for school field trips and K-12 teacher professional development activities in central Louisiana and beyond, serving 5924 K-12 school visitors with on-site field trips during the past academic year. The SEC trained 541 K-12 teachers and pre-service teachers through teacher workshops during the same time frame. Since its inception, the SEC has seen an increase in LLO's on-site outreach attendance from 1100 on-site visitors in 2004 to around 14,000 on-site visitors in 2014.

3.2.2 Needs and Future Plans

The SEC has transitioned to a regional collaboration headed by the Baton Rouge Area Foundation (BRAF), which involves Tulane University as well as all of the original SEC partners. BRAF provides an institutional umbrella under which the collaboration can continue to grow and mature. Future plans include growth in the scope and depth of the SEC's programming with an eye towards innovation as the SEC staff continues to expand the reach of the facility, reaches out to the general public more effectively and leverages the facility's potential as a unique tool for enhancing the public's science literacy and the level of interest in LIGO's pioneering research. One aspect of this mission includes the effort to involve students and teachers from several local school districts in a continuum of repeated LIGO-based experiences over a span of years. The intention of this concentrated effort is to ramp up students' understanding of STEM professions in an authentic context, while evaluating the longitudinal effectiveness of the outreach efforts. From 2004 until 2010 the SEC saw a small but steady decline in teachers attending professional development opportunities with the SEC. Recently the number of teachers involved in professional development with the SEC started to level off and then increase. In the future the SEC will need to retain the ability to involve LIGO in new and innovative outreach work as it becomes available while at the same time serving the core audiences and ensuring that the longitudinal outreach efforts are effectively managed.

3.3 LIGO Hanford Observatory

3.3.1 Past and Current Activities

LIGO Hanford (LHO) hired a full-time outreach coordinator (EOC) in 2004 and this individual operates LHO's outreach program. The site offers 21 interactive exhibits to support school ïňĄeld trips and family-oriented outreach at the site. The EOC and summer teacher interns have developed a number of portable hands-on items for use in schools and community venues. LIGO's participation in NSF's Interactions in Understanding the Universe program (I2U2) has yielded a Web-based interface for the analysis of LIGO seismometer data. The interface and its companion Web site provide a platform for student research projects in school settings. In 2014 LHO participated in approximately 12,000 outreach contacts, roughly 3800 of which were visitors to the Observatory for school field trips, public tours and public events. The remainder will come from off-site interactions at schools, at school-based family events and at community exhibitions and festivals.

3.3.2 Needs and Future Plans

Teacher professional development represents an important area of outreach for both LHO and LLO. The new Next Generation Science Standards (NGSS) call for a greater emphasis on science and engineering practices in K-12 science instruction. The new standards also elevate the importance of waves and vibrations across the K-12 spectrum. Both of these factors provide a context for LIGO to more deeply influece the practices of teachers. LHO has partnered with the nearby Pasco School District to develop a set of classroom activities that involve numerous hands-on opportunities for students in waves and vibrations. Three versions of these materials are in production – kindergarten, fourth grade and middle school. LHO partnered with Pasco on the systematic provision of teacher training for the use of these materials during the 2014-2015 school year.

LHO enlisted it's first adult outreach volunteers in 2014. These two individuals provide key intermittent support for field trips and public events. LHO also annually hires two undergraduate student assistants for one-year terms and these individuals contribute a portion of their labor to the outreach program. LHO can enlarge its service capacity in outreach by continuing to expand its labor pool through these types of means.

4 Formal Education

Traditionally, formal education is conducted in schools by classroom teachers, for students in grades K-12. EPO group work related to formal education includes the creation of standards-aligned and well-tested classroom materials, as well as training the teachers who will deliver these materials. It also includes direct work with students in classroom settings.

In the past significant formal learning about LIGO has been primarily focused on the communities local to the LIGO Observatories at Hanford, Washington and Livingston, Louisiana. In these locations, a few hundred teachers each year have been engaged in professional development opportunities offered by Observatory personnel. The first GW detections will provide an unprecedented opportunity to engage hundreds of thousands of students nation-wide in deeper learning by creating standards-aligned materials in the areas of waves and gravitation, and by training thousands of teachers nation-wide to use these materials in their classrooms.

4.1 Formal Education Unit Inspired by LIGO

The future discovery of gravitational waves will be big news - and teachers across the country will want to quickly understand the physics and astronomy behind these elusive phenomena. If we start now, we can be ready to answer questions from these teachers and their students - developing classroom ready, standards-aligned and well-tested materials that will be used when the demand is heightened by these greatly anticipated discoveries. The development cycle for these materials takes approximately three years, so it is critical that we start this process as soon as possible.

The Next Generation Science Standards present a coherent way of doing science in K-12 classrooms that is based on three interwoven strands: Disciplinary Core Ideas (DCIs), Science and Engineering Practices, and Cross-Cutting Concepts. The DCIs a most relevant to LIGO are the High School Physical Science including: PS2: Motion and Stability: Forces and Interactions; PS3: Energy; and PS4: Waves and Their Applications in Technologies for Information Transfer. Additional connections to LIGO science include DCIs in High School Earth and Space Sciences in: ESS1: Earth's Place in the Universe and connections to LIGO technology can be made through High School Engineering Design (ETS1-4). As part of PS3, students are asked to demonstrate their understanding of engineering principles when they design, build, and refine devices associated with the conversion of energy. An interferometer may be an example of this type of energy conversion.

The High School Physical Science DCIs include Newtonian gravitational forces, as well as electromagnetic waves and their properties. These are common content standards also found in the older National Science Education Standards (from the National Science Teachers Association) and also in the AAAS Project 2061 Benchmarks that are still in use in most states. Although the relativistic formulation of the laws of gravitation that predict GWs is not included in any of these standards, we can use the excitement of LIGO science to create inspiring and engaging materials that do align with the standards, and that will be readily and eagerly used by classroom teachers.

The NGSS also stress the connections between scientific ideas and the engineering practices needed to conduct the scientific inquiry. For example LIGO instrumentation is a prime example of how students could “demonstrate their understanding of engineering ideas by presenting information about how technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.” Again, the development of LIGO technologies, including lasers, seismic isolation mechanisms, and optics, provides many excellent case studies illustrating these important points. These connections can and should be made in future materials developed by EPO.

4.2 Teacher Professional Development Related to LIGO

At the present time, both LIGO Observatories (Hanford and Livingston) conduct teacher professional development programs concentrated in their local service areas. LIGO Livingston Observatory (LLO) averages about 400-500 teacher contacts each year, while LIGO Hanford Observatory (LHO) averages about 100. Each laboratory reaches out to thousands of school children through tours, field trips and classroom visits. These numbers have steadily grown from a thousand students a year to over ten-thousand students a year - indicating an interest in LIGO related science and activities. However, there has been relatively little effort to date expended to create formal educational materials or long-duration teacher professional development programs that extend beyond the observatories' local areas.

In teacher professional development LIGO Hanford currently hosts three general admission two-day workshops each summer that cover basic astronomy, waves and vibrations and computer programming. Each of these workshops is based on the NGSS framework, which has been adopted by Washington and a number of other states as the official state science standards. These workshops give participants an opportunity to view the NGSS science and engineering practices in action through informal interchanges with observatory staff. In partnership with the nearby Pasco School District LIGO Hanford has developed packets of classroom activities that address the NGSS Disciplinary Core Ideas PS3 and PS4 (mentioned above) at grades 1, 4 and 8. LIGO Hanford has provided training on these materials for groups of teachers in three Pasco elementary schools; in 2015 discussions are underway between LIGO and Pasco to broaden this professional development effort to include nearly all Pasco elementary schools.

LLO's outreach in formal education resembles the Hanford program in its aims and objectives but differs somewhat in its methods. Grant-funded projects known as Math Science Partnerships (MSPs) often use LLO and its Science Education Center (SEC) as an extended field trip and learning opportunity, while two Louisiana Universities: Southern University Baton Rouge and Louisiana Tech conduct one-week or two-week LIGO related professional development opportunities funded through the LA Board of Regents and the NSF as part of PHY 0917587. Recent external evaluation of the professional development conducted by LLO has concluded “The LIGO PD program is clearly highly regarded among its participants. In addition to high quality experiences and usefulness of the materials, teachers also reported strong learning gains in LIGO-related science concepts (waves, resonance, gravity). The success to date of LIGO professional development and the positive responses of teachers suggests that efforts should be made to expand the program's reach across the region and state and provide advanced or deeper leadership opportunities for teachers who have participated previously.”

In the past LLO and LHO both have hosted summer teacher interns through NSF's Research Experience for Teachers (RET) extension of the Research Experiences for Undergraduates (REU) program (LIGO Lab has been a REU site for years). Currently the RET component is absent from LIGO's REU award and the observatories are using other means to host summer teachers. LIGO Hanford currently serves as a host site for the STEM Teacher and Researcher program (STAR) thatâĂŹs operated by Cal Poly San Luis Obispo. Teacher internships represent a powerful tool in LIGO's efforts in formal education. These experiences provide teachers with authentic research opportunities and the chance to develop relationships with scientists and engineers, outcomes that can transform teachers' views of science and engineering practices. Teachers also work on the integration of their summer experience into their classroom teaching, producing lesson plans and other materials that LIGO can incorporate into its larger teacher professional development programs.

We encourage EPO groups to build on the existing professional development efforts pioneered by LLO and LHO in the local Louisiana and Washington regions by extending these opportunities to teachers nationwide who will be eager to learn about LIGO-related science and technology. One successful model (implemented at Sonoma State for NASA-funded programs) uses "Educator Ambassadors" - master teachers who can be trained by LIGO outreach personnel to train other teachers to use LIGO-developed classroom materials. This "train the trainer" model has been a great success for NASA-sponsored high-energy astrophysics missions, in which bi-annual training of a cohort of 15-20 master teachers has resulted in over 65,000 teachers nation-wide learning (during the past ten years) how to use NASA-developed materials in their classrooms. In July 2012, the SSU groupâĂŹs training included a two-day mini-course on gravitation and LIGO. Materials from this course and selected EVO and other videos of the lectures are available for download here.

Professional Development for LIGO should adhere closely to the ideas in "Designing Professional Development for Teachers of Science and Mathematics" by Loucks-Horsley et al. 2010.

Organizing Teacher Professional Development Workshops

Teachers typically attend professional development workshops organized either by their school districts, or by professional societies. The key professional societies in the USA are:

- the National Science Teachers Association,
- the National Council of Teachers of Mathematics, and
- the International Technology and Engineering Educators Association.

In addition, many states have their own professional societies for science and math teachers. In order to provide professional development to teachers through one of these societies, one must either be a member of the society or partner with an existing member, and then submit a workshop proposal that will be reviewed before acceptance. Deadlines occur at various times during the year, but in general are about one year ahead of the time at which the meeting is held.

Teacher Training Workshops are an effective way to reach many students. Additional leverage is gained by developing teacher training materials for use by LSC members at a wider variety of local training events. All teacher training materials should be made publicly available through the LIGO website.

Best practices for organizing teacher training events include:

- workshop is free or provides a stipend for attendance

- provide free classroom materials that are aligned to local standards
- align workshop with a specific strand that is being organized by the national society to increase the odds that the workshop proposal will be accepted
- workshop should model best practices in formal education, with an appropriate balance between lecture and hands-on activities
- work with an expert in education to ensure that the LIGO science is translated appropriately for the classroom

4.2.1 On-line Teacher Professional Development

A recent example of an online teacher training course for multiwavelength electromagnetic spectrum lessons was recently sponsored by many different NASA missions. This course offered academic credit or continuing education credit through Sonoma State University and can be viewed on the web.

Best practices for developing on-line teacher PD include:

- minimal cost for teachers to participate
- academic or continuing education credits must be offered
- a wide variety of resource materials should be developed and previously classroom-tested
- evaluation of pre- and post-teacher knowledge should be conducted
- teachers should produce a lesson plan for their classrooms as their summative experience

4.3 Partnerships with Existing Classroom Networks

We also encourage partnerships with existing networks that already have national reach into middle- and high-school classrooms. One example is the American Physical Society's Physics Quest project. Physics Quest experiments are performed by 13,000 middle school classrooms nationally, reaching over 350,000 students. EPO has been in contact with APS regarding a new issue of their comic book that includes LIGO. Help is needed to develop these ideas, and to provide input into a middle-school kit of experiments that could be distributed through Physics Quest.

For students in high school, the Department of Energy and NSF-funded I2U2 project (Interactions in Understanding the Universe) offers the potential for true scientific inquiry. LIGO's I2U2 "e-Lab" offers a Web-based interface to LIGO seismometer data for students and teachers. Hundreds of students in Washington State and elsewhere in the U.S. have undertaken research tasks related to earthquakes and other forms of seismicity using the LIGO e-lab. In doing seismic research, students benefit from resources and support that the e-Lab Web site provides. However the I2U2 project is not very well known outside of the LIGO and Fermi-lab local areas. Teacher professional development opportunities and workshops about I2U2 at national, regional and state educator's conferences would greatly improve the reach and utilization of these excellent "e-Labs." Additional existing resources that can be modified and updated to align with the NGSS include the classroom activities and demos that have been developed by Penn Stateand other members of the LIGO project. They can be accessed from the ligo.org site.

Developing curriculum for the formal education system is a major undertaking, that requires years of iteration, testing and feedback from classroom teachers. This process also requires a knowledge of state and/or national standards, as well as the principles of instructional design. For examples of well-regarded classroom materials, see the Great Explorations in `Math and Science website` and `TERC`.

Many standards-aligned and classroom tested educator's guides have been developed by the SSU E/PO groupthat relate to LIGO objects of interest such as black holes, gamma-ray bursts and supernovae. The SSU group has also developed a series of activities that teach Newton's Laws. All these activities can be downloaded from the classroom materials sections of the `Fermi` and `SWIFT` web sites.

Additional sites that feature excellent resources for the classroom include:

- `Teacher's Domain`
- `NSTA Learning Center`
- `NASA Wavelength` repository of classroom materials
- `What Works Clearinghouse`, US Department of Education repository of professionally evaluated materials

4.4 Formal Education Priorities

Below is the priority list of Formal Education Opportunities available for EPO members. As discussed the section above, the current top priority for Formal Education is to develop new classroom units for high schools that are aligned with NGSS, classroom tested and evaluated.

Additional priorities include:

- Update and revise existing classroom activities,such as the Penn State and I2U2 materials to align with NGSS
- Work with APS to develop Physics Quest experiment and Spectra comic book about LIGO for middle-school students
- Develop high-school teacher training materials that can be tested and evaluated prior to use
- Conduct professional development with high-school teachers at local, regional and/or national venues
- Expand use of existing classroom materials beyond the areas local to the LIGO Observatories
- Encourage LSC sites that hold REU grants to consider writing RET supplement proposals or explore other means by which summer teacher internships could be expanded across the LSC.
- Work with APS and other professional organisations to identify routes for publicising and distributing our LVC science summaries.

5 Higher Education

Higher education is conducted in community colleges and universities by faculty and via online settings. EPO group work related to higher education includes the creation of well-tested classroom materials, as well as training the faculty who will deliver these materials. It also includes direct work with college students in classroom settings, and research opportunities for students.

Many of the activities created by LSC members for use with senior high school students are appropriate for use by lower division college students. Others are more sophisticated, and are better aimed at STEM majors who can be expected to have more sophisticated mathematics skills. To achieve the highest leverage, EPO should aim new curriculum development activities at two distinct populations: Astro 101 students and lower-division engineering physics majors. Approximately 250,000 students take Astronomy 101 (often called "Descriptive Astronomy") each year, and for most this is the only college science course that they will take. Aiming exciting LIGO-inspired materials at this population provides an opportunity to persuade students to consider a STEM major, especially if their interest is captured in their first year in college. Lower-division calculus- based physics courses (often called "engineering physics") is taken by approximately 10% of all college students. Infusing LIGO-related science and technology into these courses is another natural avenue to widen our reach.

5.1 In Person Faculty Professional Development Related to LIGO

Professional societies such as the AAS offer face-to-face faculty workshops that accompany the semi-annual society research conferences. For example, the CAPER team and the Center for Astronomy Education often provide these workshops which demonstrate proven and effective pedagogical techniques for use in introductory astronomy courses. See the `website` for the CAE schedule.

5.2 On-line Teacher Professional Development

Sonoma State University is currently developing two on-line courses for lower-division college faculty (and AP high school physics teachers). The first course, "LIGO:Waves and Gravity is being offered July 16- August 6, 2015. The second course, "LIGO: Advances in technology" (tentative title) will be offered in the summer of 2016. Original material developed for the course can be found at: `universe.sonoma.edu`.

Best practices for developing on-line faculty PD include:

- minimal cost for faculty to participate
- academic or continuing education credits are offered
- a wide variety of resource materials should be developed and previously classroom-tested

- evaluation of pre- and post-teacher knowledge should be conducted

5.3 Resources for College Faculty

A comprehensive list of resources about LIGO that is appropriate for college faculty is a priority for EPO. Sonoma State University, in partnership with the Contemporaneous Physics Education Project (CPEP) is in the beginning stages of compiling this list. An example with a general focus on cosmology is the compendium of cosmology resources compiled by the Astronomical Society of the Pacific, for use in Astro 101 classes: astrosociety.org. A new LIGO-oriented resource list should be included as part of the update of the http://ligo.org website.

It is also important to create physics applets and other online interactive activities that feature LIGO science and/or technology. Examples from physics and astronomy include:

- physlets at the University of Colorado
- Astronomy Flash interactives at the University of Nebraska, Lincoln

After classroom testing, new LIGO activities and resources should be submitted for inclusion in sites such as:

- ComPADRE Digital Library
- MERLOT
- National Science Digital Library

5.4 Resources for College Students

Although it will require considerable resources for LIGO to create an entire one-semester course specifically about LIGO, it may be possible to create individual units which may be used to supplement existing Astronomy 101 or lower-division physics courses. Research-oriented institutions may also be able to offer an entire course as a "Special Topics" course for upper division physics majors. These types of courses may achieve wider success if offered as online or hybrid curricula, and should be extensively tested in the classroom, and thoroughly evaluated before being offered to the wider community. Due to the large numbers of Astronomy 101 students, it may be more effective to develop new activities for this mathematically-challenged population.

The Gravitational Wave Physics and Astronomy Center at the California State University, Fullerton has developed a quiz for gravitational-wave astrophysics, a series of lecture slides, space-time curvature demos, and several think-pair-share questions for introducing ASTR 101 students to gravitational-wave astronomy, based partially on interviews and tests of GWPAC undergraduate and Masters research students. Masters student Gabriela Serna has led much of the development of gravitational-wave materials along with Josh Smith, Jocelyn Read, and Masters student April Hankins. We did preliminary testing with the quiz in December 2014 and completed a full round of testing in Spring 2015.

The Sonoma State group has developed a two-semester curriculum in astronomy and cosmology for general education college students, which is now being distributed by Great River Learning. For more information, see .

Other popular web courses for students (which do not offer credit) are available through iTunes university, the Khan academy, and new initiatives such as the collaboration between Harvard, MIT and other universities that uses the edX platform

5.5 Talks and Lectures

Perhaps one of the easiest ways to reach college students is via physics or astronomy colloquia at community colleges and universities. The creation of a LIGO Speaker's Bureau section with volunteers who are expert in reaching public audiences would be a great addition to the LSC.

The American Physical Society maintains a Women Speakers List and all female LSC members are encouraged to sign up to represent LIGO topics. Similarly, the APS maintains a Minority Speakers List and also offers travel grants of up to $500 to the participating institution to support invited minority lecturers. The American Astronomical Society sponsors the Harley Shaplow Lectureships and any LSC member with an interest in the more astronomically-related LIGO subjects should consider applying for this program.

5.6 Summer Research Programs

Authentic research experiences in LSC-groups provide an important introduction to disciplinary socialization, which has been shown to be a key factor in the retention of (especially under-represented) students in STEM majors (Clewell et al. 2005). Proven examples include:

- Research Experiences for Undergraduates (REU) programs that are routinely offered at several LSC member sites, including: the University of Florida, University of Texas Rio Grande Valley, Louisiana State University,
- CalTech's SURF (Summer Undergraduate Research Fellowships) program
- Sonoma State University's Global Telescope Network which provides free access to both northern and southern telescopes for student use to observe LIGO-related astronomical objects

The University of Florida's REU program operates internationally: this program encourages participating American students to learn about the growing internationalization of research and to establish scientific contacts beyond the borders of the United States. Students intern at gravitational wave research facilities in Australia, Europe and Asia as part of this program. `http://www.phys.ufl.edu/ireu/`

5.7 Higher Education Priorities

Below is the priority list of Higher Education Opportunities available for EPO members. As discussed in the section above, the current top priority for Higher Education is to develop new LIGO-related classroom activities for introductory Astronomy courses that are classroom tested and evaluated.

Additional priorities include:

- Update and revise existing college student activities, such as those originally created by Penn State
- Offer college faculty training workshops

- Provide additional college student internship activities in LSC groups, especially for students traditionally under- represented in STEM
- Contribute to the development of LIGO-related resource page for college faculty use
- Collect ideas for and summaries of previous undergraduate research projects

6 Informal Education and Public Outreach

Informal education refers to content-rich activities that are conducted outside of school hours. For the LSC, these activities range in scope from local initiatives that engage LSC staff and students in delivering informal talks and workshops to astronomy societies and science festivals, to coordinated global activities such as the citizen science program Einstein@Home. Informal education also includes after-school programs, web-based activities, and exhibits at science museums. This section of the white paper also includes public outreach such as social media, mainstream media (press releases and conferences), materials developed for distribution to the general public and large public lectures.

6.1 Visual Media

As the era of detections nears, it is vital that the LSC develop a suite of visual media clips that can be used by mainstream and online media. The clips that are needed include (but are not limited to):

- animations of the most likely GW events: inspirals, bursts, and other results from numerical simulations
- overview shots of the observatories
- diverse scientists working on various types of hardware
- interesting shots of the hardware systems

All clips should be available in various resolutions, but HD is required for use by mainstream media. It is also important to produce clips in various lengths - up to 30 seconds for use by mainstream media, and about 2 minutes of narrated stories for youtube audiences and to be used in press releases. Additionally "B-roll" is required to support media releases. Press choose snippets of B-roll to talk over in news reports. Best practices in this area include NASA's Scientific Visualization Studio which is a repository of all the visual media developed to support NASA press conferences. Note the many different formats and lengths of animations plus still images available for each release. The LSC has already excelled in creating longer explanatory videos such as *Einstein's Messengers*, *LIGO: A Passion for Understanding*, and *LIGO: Generations*.

6.2 Web Media

The power of the internet to reach a wide audience is almost unmeasureable. We should continue relations with established comics such as PhD Comics.com, the HowToons.com, comics from APS, the

Dark Matters, and the authors of animated comics such as the Higgs Boson Explained and encourage them to continue to feature LIGO in their offerings.

An excellent example already developed by the LSC is the 'virtual tour' of the LIGO observatory developed by the LSC group at the Eotvos University in Hungary. Additional related work includes the outstanding videos at scienceface.org which highlight the challenges of constructing and commissioning the second generation detectors.

Additional opportunites for web media promotion include talk at events such as TEDx: an independently organised TED event. These events can achieve extremely high profile and impact and are becoming increasingly common in other fields of science. The Eotvos University group has put together a useful summary and guide to the most popular science education and video sites. The document can be found on the DCC.

6.3 Audio Media

As the detection era nears, it is also extremely important to curate a collection of the best audio clips that convey the "sound" of gravitational waves that are likely to be detected. The EPO group should establish a website and solicit the best clips from LSC members. Gravitational waves are very often described as the "sounds of spacetime" so our websites and press materials should include excellent examples of GWs converted into audible sounds. NASA press audio clips in a similar vein include those which set a gamma-ray burst to sound and the "heartbeat" of the smallest black hole discovered by RXTE.

6.4 Multimedia

The LSC has already supported the highly successful *Einstein's Cosmic Messengers* multimedia concert, conceived by renowned musician and composer Andrea Centazzo and LSC member Michele Vallisneri. Additional examples include the original musical compositions by Nolan Gasser "GLAST Prelude" and the "Cosmic Reflection" symphony which was accompanied by multi-media presentations written by Pierr Schwob. Both were, originated for NASA's Fermi mission.

Additional instructive examples include Kip Thorne's work on Interstellar (for which the LIGO scenes were cut) and its popular book *The Science of Interstellar*. Examples from other fields are *The Mighty Thor* and *The Martian*.

6.5 Social Media

Social Media accounts maintained by the LSC include Facebook (LIGOScientificCollaboration) and Twitter (@ligo). LSC EPO members are encouraged to contribute to posting on these pages, as a steady flow of updates is essential to continue to build the audiences for each. As of 10/20/15, there are 1203 "likes" on the Facebook page and 2689 followers on Twitter. Potentially these audiences could be much larger. For example, @NASAFermi has over 41,000 followers on Twitter, Fermi Gamma-ray Space Telescope has over 28,000 "likes" on Facebook, and CERN has over 1.25 million Twitter followers for @CERN and over 468,000 Facebook fans. LSC members who have content that they want posted to the LSC's Twitter or Facebook accounts can send news and related items about collaboration members to lsc-epo@ligo.org.

Reddit is another web platform that is being utilized by the LSC. The Reddit AMA (Ask Me Anything) forum organized in February 2015 by Maggie Tse was a great success, and she is already planning additional similar activities for the future. Involvement by LSC EPO members is strongly encouraged. Over 3400 readers participated and over 500 comments were received during this inaugural AMA that featured 19 LSC members.

The most widely read LSC scientist blog is Living LIGO by Amber Stuver from LLO. Although it is not an official LIGO publication, it offers clear explanations of questions of interest to the LIGO-attentive public, as well as personalizing the LIGO project. This is an excellent example of individual effort that has an impact that greatly exceeds its cost, and similar efforts by a diverse set of LSC scientists are greatly encouraged.

As well as maintaining individual blog sites on the web, members of the LSC EPO group periodically monitor other blog traffic looking out for stories or comments relevant to gravitational wave science (particularly those which are overtly critical towards or misrepresent our field. While some such blog comments emanate from 'fringe' sources and are not worth engaging, others are from more respectable sources and/or feature questions that are motivated by genuine scientific curiosity but may belie some fundamental misunderstanding. Responding to these bloggers can be worthwhile, clearing up misconceptions and spreading positive attitudes about LIGO science. The EPO group welcomes the help of more LSC members to assist our 'blog squad' with this activity.

The EPO group also receives occasional notifications from the collaboration when a website inaccurately portrays the science being conducted by the collaboration. When a blog entry is noted that should be responded to, the Blog Squad uses a standard statement that summarizes LIGO science and can be used for most purposes with slight modification:

"LIGO (funded by the National Science Foundation), as well as other worldwide gravitational wave projects, is actively engaged in a scientific endeavor to search for the gravitational waves predicted by Einstein's general theory of relativity. We look for gravitational waves from a variety of astrophysical sources, such as coalescing binary neutron stars and black holes. The nature of the gravitational waves is such that a detectable gravitational wave coming from a galactic or extra-galactic source requires an immense amount of energy (over one trillion, trillion gigatons of TNT). It is highly unlikely that detectable gravitational wave amplitudes could be produced from anything other than massive and large-scale astrophysical processes."
Your Name
Your Institution
LIGO Scientific Collaboration

The Blog Squad maintains a list of blogs that are monitored periodically along with the template response on the EPO wiki.

6.6 Computer Games

The LSC has already created many computer games. Some of these are already being updated to run on modern platforms. Notable contributions include: the UK Cardiff group's *Black Hole Hunter* and Birmingham group's *Spacetime Quest*. The University of Birmingham has defined the gold standard for LSC game creation through their unique online platform www.gwoptics.org that provides and distributes information, media and software tools for teaching and public outreach related to gravitational waves. Interactive web activies found on www.gwoptics.org include:

- *Black Hole Pong* is an arcade-style game, a re-edition of the classical game Pong, with black holes and stars in place of paddles and a ball.
- GW Ebook: A short selection of texts written by students introducing gravitational waves and the various topics of GW detector design.
- Finesse and Simtools: One step away from the games and simple interactive simulations as documented by Freise et al "Frequency-domain interferometer simulation with higher-order spatial modes" CQG 21 (2004), one of the main interferometer simulations in the field.

Best practices for future game development include: a) needs assessment for target audiences, b) development on modern platforms to ensure portability and sustainability, and c) comprehensive user testing and feedback prior to release.

Excellent examples from other fields include the LHC Android App, and sky visualization tools such as Google Sky and Microsoft's World Wide Telescope. It may be many years before GWs can be located to sufficient precision to build skymaps, but these types of tools may be useful in the future.

Another area that is developing rapidly is the use of Virtual Reality. With the advent of Google Cardboard, VR has become available to anyone with a smartphone. It may be possible to adapt the state-of-the-art software used to design LIGO to produce the 3-D visualization files needed to run on VR platforms.

6.7 Citizen Science

Einstein@Home, developed by the Hannover group, is one of the best examples of citizen science today. Originally designed to search for gravitational wave signals during personal computer idle time, the software has discovered a total of around 50 new radio and gamma-ray pulsars to date in data from the Aerecibo radio telescope and NASA's Fermi Gamma-ray Space Telescope. The long-term goal is to make the first direct detections of gravitational-wave emission from spinning neutron stars. LSC EPO members are encouraged to join this project and to promote it at public events.

There is a current LSC collaboration with the Zooniverse citizen science team to develop a LIGO Glitch Zoo project.

6.8 Exhibits

One of the most prominent achievements by the EPO group has been the design, delivery and display of two NSF-funded exhibits, entitled 'Astronomy's New Messengers' showcasing gravitational wave science. These "large" and "small" exhibits have traveled around the US, with particular success at New York City's annual World Science Fair. Similar, smaller exhibitions have also been successfully displayed at various events elsewhere around the world.

Permanent museum exhibits are very costly (millions of dollars) and are typically about 5000 square feet. These types of exhibits are usually developed by the museums in situ. Traveling museum exhibits, while also expensive, are typically 1000 square feet, and can reach much wider audiences as they travel around the country. This is the size of the larger version of âĂŸAstronomy's New Messengers.' The smaller version (about 200 square feet) proved to be very versatile, and the development of additional and updated similarly sized exhibits is a priority for future LSC EPO. Recently, the LSC has begun to use the smaller size of exhibit in booths at scientific and diversity conferences.

Conference booth sizes start at 10 x 10 feet and the LSC rented a double-wide booth (20 x 10 feet) at the recent IAU meeting. Although booth rentals start at about $3500 for a 10 x 10 space, copies of this type of booth display are relatively inexpensive and could be created by LSC groups for use at local conferences. Many of the resources needed to create this type of exhibit are available on the EPO Wiki. A typical exhibit booth could include:

- A pop-up LIGO banner
- A portable backdrop on gravitational-wave astronomy
- A small table-top Michelson interferometer
- Computer displays or touch screens for showing multimedia and/or running games software, such as movies and animations on gravitational-wave astronomy (many links on the EPO wiki), Black Hole Hunter, and Black Hole Pong.
- Handouts about LIGO science and technology, including flyers with science summaries
- Games and puzzles (e.g. mazes, crosswords, word searches) suitable for younger kids. Several examples now exist on the EPO wiki but a wider range would be useful e.g. 'dot to dot' or 'spot the difference' puzzles, or simple line drawings for younger visitors to color
- Simple 'hands-on' activities suitable for younger kids, to convey basic concepts about gravitational waves and spacetime include a slinky to demonstrate fundamental wave properties, stretched rubber or lycra sheet to allow a simple demonstration of spacetime curvature, or an adaptation of Fermi's "Make your own pulsar" activity with 2 inspiralling pulsars.

6.9 Printed Materials

The LSC has produced a wide variety of printed materials that are aimed at various audiences. Especially notable examples are the LIGO magazine and the LVC Science Summaries. The LIGO magazine, edited by Andreas Freise, is an outstanding effort, and LSC EPO members are strongly encouraged to contribute to future issues. It is a high visibility product with great accessibility by the general public and value within the LSC.

A significant EPO activity has been the creation of an online 'Science Summary' webpage, aimed at the level of a scientifically literate non-specialist, to accompany new LSC publications. Dozens of LSC and Virgo members have written science summaries that are now posted on ligo.org. Standalone hardcopy versions of these science summaries are also being produced and archived on the wiki, for distribution at e.g. science fairs and other outreach events. Additional public friendly Science Summaries of LSC publications exist in both online and pdf flyer formats. Participation by LSC EPO members in the creation of new science summaries is a high priority activity. In particular we welcome suggestions for new ways (e.g. via email lists, arxiv.org, astrobites.com, or other online communities) for advertising and distributing these summaries to help maximize their impact.

6.10 Connections to Art, Theater, and Dance

At the March 2015 LVC meeting in Pasadena, attendees were treated to a display of art by Jim Barry, who illustrated many aspects of LIGO science with his imaginative creations.

The LSC group at RIT has recently premiered Astrodance which tells the story of the search for gravitational waves. Astrodance combines dance, multi-media, sound and computer simulations to engage the audience in the understanding of science through artistic expression. The general public was also invited to discuss cutting-edge scientific questions with the scientists participating in the project.

Other notable examples include Dance Your PhD, and the innovative dance performance The Matter of Origins directed by Liz Lerman which explores the origins of matter and the mind's capacity to understand beginnings from the quantum to the cosmic scales.

Although this area is not a priority, as time and talent permits LSC EPO members are encouraged to develop similarly creative endeavors.

6.11 Multilingual Outreach

International members of the LSC are translating resources from the ligo.org website into languages other than English, including Hungarian, Spanish, and others. A good example is provided by the Balearic Islands Relativity Group that has been working on increasing the gravitational waves outreach resources available in Spanish.

Some EPO resources may also benefit from national or local 'tweaks' to highlight areas of particular relevance (e.g. alignment with national/local specific school science curricula or highlighting of contributions from national/local LSC groups or individuals). LSC groups are encouraged to contribute to this effort.

6.12 Outreach to Children

Additional resources are needed to do effective outreach to children who are too young to comprehend the details of gravitational waves, but who are nonetheless intrigued by astrophysical objects such as black holes, etc. Many of the attendees at science festivals bring young children who can be engaged by activities such as:

- line drawings suitable for coloring
- join-the-dots and 'spot the difference' puzzles
- word searches, anagrams and crosswords
- quizzes and 'amazing facts' sheets

Another possibility, although one requiring considerably more effort, is the production of a LIGO comic aimed at younger children. This could be produced regularly (e.g. every few months) as an ongoing feature (perhaps starring our own LIGO characters (or as a one-off outreach effort). A similar project that is being discussed is an issue of Spectra comics and a Physics Quest kit for middle school students (see section 4.3).

6.13 Priorities for Informal Education and Public Outreach

As discussed earlier, the top priority for public outreach is to assemble a collection of video and audio clips suitable for publicity when the first gravitational wave detections are announced. This includes the preparation of FAQs, talking points, and science summaries suitable for a general audience and by journalists - in support of the LSC "Discovery Plan."

Other priorities include:

- Increase the frequency and reach of our social media activity - principally Twitter and Facebook
- Work with the APS and other professional organizations to identify routes for publicizing and distributing our LVC science summaries, and other scientific output, to a wide public audience.
- Creation of LIGO-oriented materials for younger children to be distributed at science festivals, open houses, etc.

We invite LSC groups and individual members to identify from the above list of informal education priorities activities to which they would be willing to contribute.

7 Professional Outreach

7.1 Professional Outreach and Advocacy

Advocacy is a part of outreach and education that targets audiences that may or may not be literate in gravitational wave physics, but they can and do have influence on the professional evolution of the field.

There are a variety of audiences for advocacy efforts. The goals of advocacy are to educate and inform anyone whose role gives them the opportunity to interface with gravitational wave physics, either at the role of individual scientists and PIs engaged in gravitational wave research, or in policy making that may have bearing on the future of the field. These audiences include, but are not limited to:

- other scientists, particularly colleagues in home departments, as well as scientists in fields that have the potential to overlap with gravitational wave physics (astronomy, optics, computational physics, etc.)
- the broader academic community, including university administration, as well as program officers at funding agencies and/or foundations
- government and legislative officials and staffers

The shape and form of advocacy efforts can take the shape of direct meetings, but also encompasses organizing special events and sessions at national meetings, developing collaborative meetings between other scientists and gravitational wave communities, and encouraging broad-based engagement in giving colloquia and other presentations.

7.2 Priorities for Professional Outreach

Priorities for Professional Outreach fall into two main and one additional category:

- Outreach to scientists at professional conferences. Examples include the LSC booth at recent meetings such as IAU, and large AAS meetings. Other possibilities include the HEAD/AAS meetings, and the March and April APS meetings.
- Outreach to government officials. To this end, the American University group is leading the effort to develop printed materials to give to public officials. It is also important to craft "the ask" which is what is expected when delegations meet with elected officials.
- An additional priority would be for LSC members to get actively involved in governance for professional societies and divisions such as AAS, HEAD/AAS and APS/DAP.