BUILDING A REGIONAL INFRASTRUCTURE FOR SCIENCE AND SCIENCE EDUCATION:

SUMMARY EVALUATION REPORT OF THE LIGO SEC PARTNERSHIP

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PREFACE

LIGO SEC is the Science Education Center (SEC) linked to the Laser Interferometer Gravitational-Wave Observatory (LIGO) in Livingston, Louisiana. Funded by NSF, LIGO SEC's aim is to help make the cutting edge science of LIGO accessible and inspirational to the public. This is a daunting challenge as the science behind LIGO is very abstract but also very compelling; the location of the facility is also very remote.

Inverness Research (IR) has served as the external evaluator for LIGO SEC since its inception in 2004. During Phase I, IR served primarily as formative evaluators, monitoring the development of the theory of action and providing feedback about programs and approaches. During Phase II[1], beginning in 2009, IR moved into a more summative role[2], focusing on the design and accomplishments of the evolving LIGO SEC Partnership involving Southern University Baton Rouge (SUBR), San Francisco's Exploratorium, and the Baton Rouge Area Foundation (BRAF).

This is a summary report that highlights key findings and important design features of LIGO SEC II, with emphasis on the partnership that has evolved into a regional infrastructure to support science education that is linked to cutting edge science research. We think the evolution and design of the LIGO SEC Partnership can serve as a model for other similar Education and Outreach Centers associated with highly theoretical and remote science, technology, engineering, and mathematics research facilities.

The report is organized into the following sections:

I. Major Accomplishments. A very brief overview.

II. Benefits of the LIGO SEC Partnership for Key Audiences. Highlights from studies of ways that university undergraduate and graduate students, as well as K-12 teachers in professional development programs, benefited from LIGO SEC.

III. The Design of the LIGO SEC Partnership.

A. An examination of the **design challenges** inherent to linking science education centers to science research centers.

B. A portrayal of the **structures and strategies that formed the Partnership to address these challenges**, the relationships among and roles of the partners, the unique assets they bring to the work, the capacities they have grown together, and their contributions to the Partnership and ultimately to the regional infrastructure.

IV. Lessons Learned. A short distillation of practical lessons based on observation of the evolution of LIGO SEC over time.

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[1] For the grant *LIGO Science Education Center Partnership (SUBR)*

[2] The appendix summarizes Inverness Research's evaluation tasks and data sources. Additional information can be found in progress reports and the Committee of Visitors memo, available from Inverness Research on request from www.inverness-research.org.

I. MAJOR ACCOMPLISHMENTS

Our study of LIGO SEC Phase I in 2008 concluded with this perspective:

> *From our perspective, LIGO SEC has the potential to become an infrastructure for supporting science education improvement activities throughout Louisiana. That is, LIGO SEC can provide opportunities for increasing the capacity of those engaged in science education to improve science teaching and learning. LIGO SEC offers programs, resources, connections, and leadership for helping teachers and others employ informal approaches and supports to their classroom science teaching that reflect the ideas and inspiration of the LIGO gravity wave experiment. The unique asset of the LIGO experiment sets the stage for real-world, relevant, and cutting edge science that can be translated to the public through the engaging hands-on exhibits and activities.*

Evidence from five years of study of the LIGO SEC Phase II model and its impact suggests that the LIGO SEC Partnership has indeed evolved into **an incipient infrastructure that supports science education improvement in the Baton Rouge area, statewide and beyond**. This outcome represents valuable return on NSF's investment.

Three achievements of LIGO SEC II contributed to the building of this infrastructure:

- Designing **"win-win" arrangements among multiple key partners** that draw on the assets and capacities of each partner to support improving science education in the region. Each partner adds value to the work of the other partners by contributing unique resources, skills, and capabilities that enriched and/or amplified the work of the other partners.

- **Identifying and prioritizing audiences** that can benefit the most from the LIGO SEC-SUBR Partnership model. The project is better positioned now to focus its resources and energies on targeted audiences (i.e. LIGO docents, K-12 teachers and their students, graduate students), while still being inclusive of other audiences.

- Providing valuable **service in the community, the region, and beyond** as a science education improvement interface.

II. BENEFITS OF THE LIGO SEC II PARTNERSHIP FOR KEY AUDIENCES

LIGO SEC II has served a very broad audience, including the general public, professional organizations in STEM, other research centers, K-12 parishes and schools, university undergraduate and graduate students, and K-12 students. Our evaluation study targeted two audiences of particular importance to the success of the Partnership and which also represent a strong return on the NSF investment. One audience comprises university students, both undergraduates and graduates, that LIGO SEC leaders wanted to inspire and

train as future scientists and engineers. The second audience, K-12 teachers, reflects the Partnership's mission to support education improvement broadly throughout the region.

This section summarizes our independent data collection and observations as well as perceptions of a Committee of Visitors organized by Inverness Research for a site visit to LIGO SEC in 2013[3].

Benefits to university students

The LIGO SEC Partnership serves university students both through special programs, such as the Docent Program, and through regular university programs and courses that integrate LIGO science. The Committee of Visitors noted in their report that the re-design of some university courses as part of the Partnership has resulted in strengthening the Southern University Baton Rouge (SUBR) STEM programs and laboratory experiences, including undergraduate programs in physics and mathematics, teacher preparation, and graduate studies in STEM and STEM education.

Undergraduates in the Docent Program

The LIGO SEC/SUBR Partnership regards the Docent Program as a "signature program," particularly with respect to reaching students traditionally under-served in STEM fields and science education. The Committee of Visitors noted in their findings that the Docent Program was growing and had become integral to the work of LIGO SEC. As of the writing of this report, nine cohorts of docents have come through the training and experience.

The program has been very successful overall. In 2013, 31 student docents completed a survey about their motivations and experiences as LIGO docents. Highlights include:

- LIGO has had a large **influence on the college, job and career decisions** of a majority of the responding docents, with its greatest influence on career decisions of those who are pursuing a STEM education career path.
    - The great majority of respondents (89%) report that LIGO positively influenced their interest in pursuing a STEM field.
    - All respondents majored in a STEM subject or STEM education and would like to work in those fields.
    - Half of the docents who responded to the survey are in graduate school or have completed a graduate program.

- LIGO taught the docents how to **effectively communicate about STEM concepts** and skills (96% say it had a lot or great deal of influence), provided them with **experience** (88%) and with **knowledge and skills** (84%) **they could not have gained anywhere else.**

[3] See the appendix for the composition of the committee as well as data sources.

- Many (77%) also report that their experience as a LIGO docent **changed the way they interact with their community**, e.g., through improved public speaking skills and better ability to talk with youth about how science can impact the community. Several could provide concrete examples of **engaging children in science** while serving as LIGO docents.

Southern University of Baton Rouge (SUBR) is a historically black university, and most docents are of African American descent. Thus the empowering aspects of the docent experience are particularly important in contributing to broadening participation of underrepresented groups in STEM and science education. The partners were especially encouraged to learn recently that a former docent was hired in a technical position at LIGO operations, and the PI has expressed hope to hire more in the future.

Graduate students

In 2014, IR conducted in-depth interviews with six graduate students associated with LIGO SEC; these are also SUBR students from groups under-represented in STEM. The interviews focused on their experiences at LIGO, on the extent and ways LIGO influenced their graduate work, and on their future plans. Overall, the graduate students we spoke with were profoundly influenced by their connection with the LIGO SEC, particularly with respect to their research and their perspectives on teaching and/or communicating science.

Highlights:

- Working with LIGO provided a focus for their studies or increased their interest in doing more work with learning in museums.

- One former graduate described how working with LIGO helped her understand and experience science in new ways, which has influenced her current work with teachers.

- Working with LIGO SEC influenced the students' thinking about quality science teaching, in particular the role of inquiry in science teaching and learning.

- One graduate said that being involved in LIGO SEC improved her science communication skills.

- Students noted that participating in LIGO SEC created new professional connections, increased their confidence, and inspired them to "pay it forward," motivating them to contribute to STEM education outreach work in their future careers.

Benefits to teachers in professional development programs

SUBR and LIGO SEC have partnered with the Exploratorium on the design and delivery of teacher professional development (PD). The Project MISE (Modeling Inquiry Science Education) program consists of a summer workshop followed by academic year interaction.

To date, nine cohorts of 20 - 30 teachers have participated in Project MISE. A new leadership-focused program for MISE graduates started in 2014, aiming to develop teachers' leadership skills so that they become advocates for inquiry science teaching and learning in their schools.

Findings in this section are based on three data sources: A reach and impact survey of teachers administered by in 2011, interviews with teacher leaders (2014), and the internal evaluation results that LIGO SEC gathers from its PD program activities.

General findings

- We have found that the Exploratorium's highly effective training and pedagogical approach to "LIGO Science" permeates all PD for teachers in the Project MISE and other partners.

- A ripple effect occurs when LIGO SEC invests in supporting teachers over time. Teachers who get immersed in what LIGO SEC has to offer generate waves of influence, which results in more teachers and students reaping the benefits.

- The ongoing work with teachers has created a community of educators in the region who are dedicated to inquiry science teaching, and who are increasingly able to incorporate the physics concepts of the LIGO experiment into their classroom teaching.

The Committee of Visitors noted in their findings, as well, that professional development through MISE is far reaching and increases the number of regional/Louisiana state (and beyond) teachers and teacher leaders who are knowledgeable and have skills in teaching LIGO science concepts.

More detailed findings

- Teachers report that their knowledge of LIGO-related science increases as a result of their participation. 92% of teachers responding to the survey indicated the quality of PD is good or excellent.

- Over one-half of the teachers who participate in PD had taken their students to the LIGO SEC facility. Of those, 95% indicated the quality of the field trip was good or excellent.

- About half of the teachers incorporate LIGO science in their classrooms.

- Over one-half of teacher participants engage in leadership at their grade levels and in science departments.

- A majority would like to learn more about how to teach LIGO science in their classrooms, and about the LIGO experiment itself.

- 100 % of the respondents consider LIGO SEC to be a good or excellent resource for improving science education in the region.

- Teachers told us that LIGO SEC has created a community of educators they can connect with. Those involved in parish partnerships feel a community both within their parishes and with others outside of their parishes.

- Teachers report that they appreciate the teacher- and student-centered approach to the PD and resources. They have a strong feeling that the staff listens to and are responsive to the interests and needs of participating teachers.

III. THE DESIGN OF THE LIGO SEC II PARTNERSHIP

How did the LIGO SEC Partnership evolve to the extent that it could provide important benefits to multiple audiences and evolve as an important regional infrastructure for science education? In this section we examine the challenges of designing education programs that link to large facility science centers[4], and we portray the structures and strategies integral to the LIGO SEC II partnership.

A. DESIGN CHALLENGES

When NSF funds basic science and science education, the foundation is assuming that grantees can create arrangements that connect the science research and education outreach enterprises in fruitful ways. A number of design challenges are inherent to the work of making such arrangements. Here we outline key design challenges faced by LIGO SEC II. They provide context for understanding the setting in which the LIGO SEC – SUBR Partnership is working and the audiences it has attempted to engage.

Some challenges are inherent to NSF's charge and thus were foundational to the LIGO SEC II partnership:

The science

The science research of LIGO—detection of gravitational waves—is abstract, mathematical and theoretically complex. The LIGO facility and the LIGO endeavor is astonishing and fascinating. But how can LIGO SEC tell its story in a way that makes that science accessible to the public, particularly to youth? How do K-12 and postsecondary educators translate the scientific research for their students?

There are underlying physics and astrophysics concepts and science/engineering practices related to the LIGO experiment that are accessible and do make sense to teach—particularly in the context of the *Next Generation Science Standards*[5]—and that are more

[4] LIGO SEC Phase I was funded in parallel with LIGO, and LIGO SEC Phase II was funded in parallel with the funding of a second phase of LIGO, Advanced LIGO, featured in *Science* (See Cho, 2015).
[5] These were coming on line concurrent with Phase II of LIGO SEC.

accessible to diverse audiences than the actual research. The challenge then is this: Which concepts and practices are most appropriate for which audiences? How are they best taught? How do they tell the story of LIGO?

Institutional interfaces

Creating the interface between the science at LIGO and nearby institutions of higher education is a real design challenge. The science and educational opportunities at LIGO and LIGO SEC are alluring for those IHEs that are interested in what they have to offer. But how to structure the interaction? What is the nature of the interfaces (arrangements) that have evolved? What makes them effective?

The geographic location

The LIGO and LIGO SEC facilities were built in a remote, sparsely populated location in Livingston, Louisiana. Like many Science Technology Centers, the facility packs a "wow" factor that makes a deep and positive impression on visitors. The spaces are dramatic—and they are also highly sensitive. There is very limited access to the research facility due to the nature of the experimentation (e.g., when the experiment is running the vibrations from machinery and autos can interfere with the data and results). What is the capacity of such a facility to host programs and events? How can the facility maximize opportunity for learning about LIGO science without physically going to LIGO?

Multiple diverse audiences

The Center has the potential to serve multiple and diverse audiences, for example, K-12, postsecondary, the general public, other science education organizations. Are some audiences more effectively served than others? How does a Center decide who to serve and why? How are they reaching and serving traditionally under-served audiences?

Additional design challenges emerged over time as the LIGO SEC Partnership evolved:

Scaling to meet demand

As audiences' demand for more access to LIGO SEC grows, the demand puts stresses on the staff, leadership, resources, and facilities in Livingston and at Southern University. How does the Partnership function to continually build capacity, including serving audiences "off site"?

Expanding workforce and STEM field preparedness

Phase II of LIGO SEC has demonstrated that when undergraduates and graduate students are engaged with LIGO SEC and/or the LIGO research itself, the experience influences their educational and career trajectories toward STEM. Given that the majority of this population of students is from underrepresented groups in STEM, this development calls

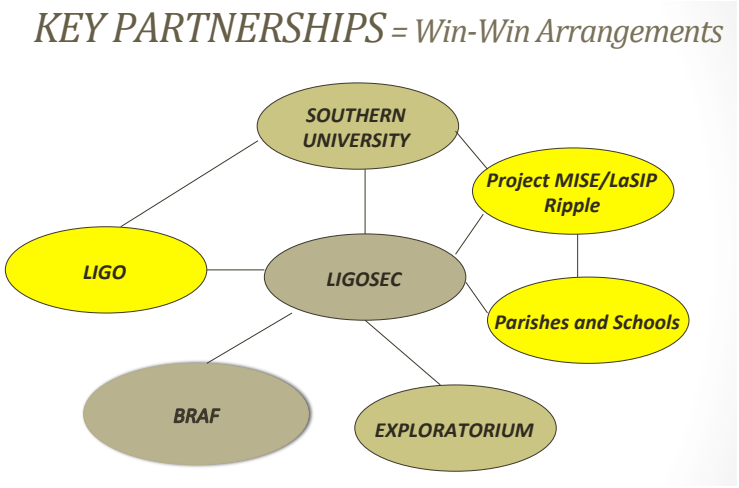
for more attention and resources. How can the LIGO SEC Partnership expand the pipeline opportunities for more under represented undergraduates and graduate students?

B. EFFECTIVE PARTNERSHIP STRUCTURES AND STRATEGIES

The LIGO SEC II Partnership and its activities have been tested and solidified through ongoing cycles of development and evaluation over nine years' time. Certain structural and programmatic designs stand out as contributing to meeting the design challenges described above and ultimately to form a new regional infrastructure.

The **LIGO SEC Partnership design** is the core overarching structure for meeting many of the design challenges. The linked partners are represented in Figure 1 below. We consider them to be the engines that fuel improvement and expansion of the LIGO SEC work and impacts.[6]

Figure 1. Key Partners



Win-win arrangements among key partners

Over the years, the institutional partners' roles and contributions to the overall effort have become more strategic, defined, and have grown to expand and deepen impacts on participants, in particular the SUBR docents and classroom teachers. Below we briefly outline the key contributions each partner makes to produce synergistic "win-win" arrangements.

The LIGO Science Education Center building sits across a patch of grass from the Laser Interferometer Gravitational-wave Observatory (LIGO), the research facility where

[6] The partners portrayed in this graphic are core partners, with those in darker shaded bubbles funded directly and those in yellow bubbles funded indirectly through partnership work. There are additional peripheral partners. LaSIP, a state funded program, is no longer in existence but played an important role early in Phase II.

scientists from all over the world work to measure aspects of the cosmos. The LIGO SEC itself was explicitly designed and built to be an education facility. It has an amphitheater where introductory movies such as "Einstein's Messenger" are shown to those new to LIGO, and where speakers share their research and insights during the successful public series, "Science Saturdays." The large exhibit hall holds over 40 interactive, hands-on exhibits that relate to the science of LIGO, designed and built by the Exploratorium. It is here where docents from SUBR assist the LIGO SEC staff in facilitating the many field trips for students and tours for the general public. A large laboratory classroom sits adjacent to an entry space where school groups, teacher groups and visitors are engaged in activities. Some displays and exhibits are permanent, and some change according to new designs from the Exploratorium and/or other resources.

Southern University Baton Rouge (SUBR), a historically black college, has continued to be the key Higher Education partner. The Partnership arrangement between SUBR and LIGO SEC is based on a long history of establishing trust and respect for what each institution and the individuals at the respective institutions bring to the table. With an established and respected history of integrating LIGO into their science, mathematics, and education programs, SUBR also fuels the Docent Program, one of the most influential LIGO SEC-related programs for undergraduate students. Through redesigning courses within the education/teacher preparation and science departments, SUBR provides the primary pool of graduate students from education, physics and mathematics that have landed at LIGO for their master's degree or dissertation research. The University has also secured funding of its own to house a "satellite" LIGO Lab (known as the "Inquiry Lab") where classes can experience smaller renditions of LIGO SEC exhibits that teach the physical and earth science concepts, as well as mathematics. In summary, there has been a long-term rowing win-win relationship between the university and the lab.

Project Modeling Inquiry Science Education (Project MISE). SUBR works in tandem with staff at the LIGO SEC to design and deliver professional development workshops to PK-12 teachers from local parishes and schools within the region and beyond, especially through Project MISE. Through these and other LIGO SEC professional development opportunities, teachers have an opportunity to reflect on, revise, and share the work they are doing with other teachers within their local regions and beyond.

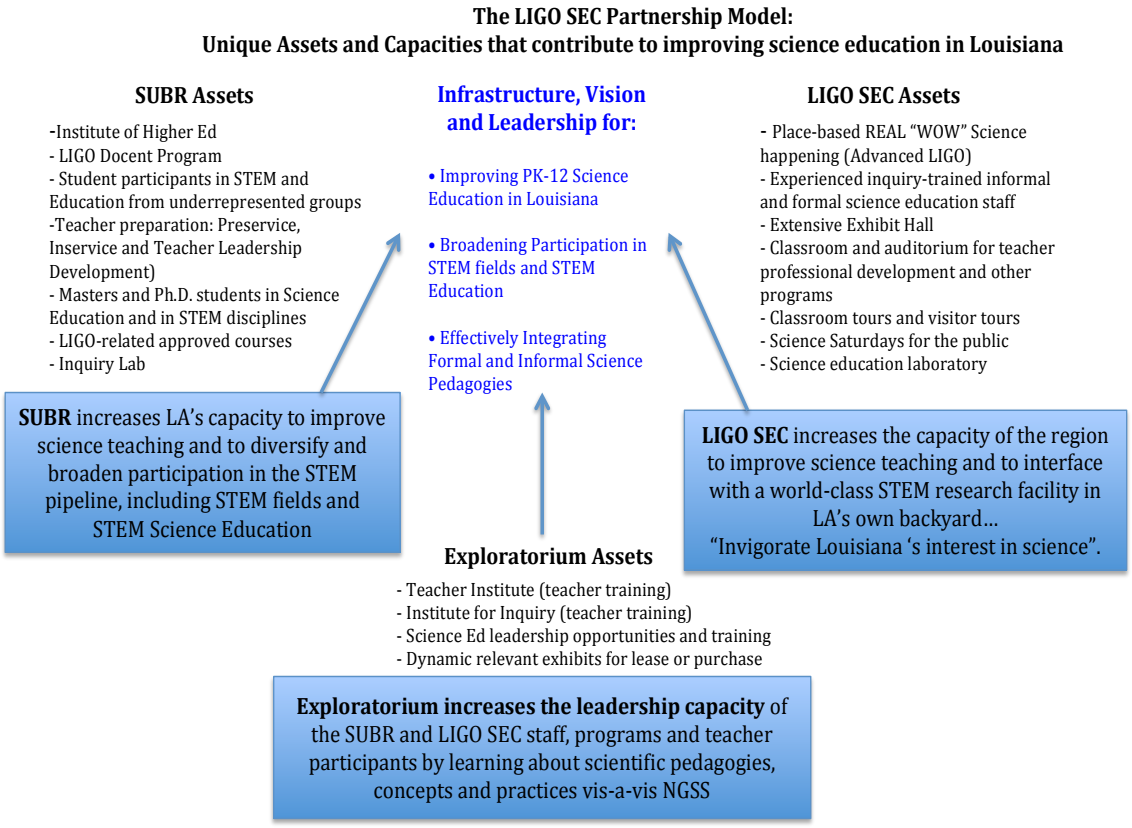
The Exploratorium, also an original and core partner of LIGO SEC, brings to the effort a deep research-based approach to informal science teaching; teacher leadership workshops that focus on inquiry-based pedagogies with particular emphasis on the physical sciences; opportunities for LIGO SEC staff and leaders to both participate and bring their knowledge and practices to a larger audience through presenting their own work; a large library of exhibits and curriculum that is made available for lending or purchase to equip the LIGO SEC facility with excellent exhibits; and the potential to create new exhibits and materials for LIGO SEC. The Exploratorium also assists LIGO SEC, its staff, and its teacher participants with the creation of "snacks," which are smaller versions of the exhibits. Snacks demonstrate the same concepts but can be easily and economically created and/or transported to classrooms.

The Exploratorium's participation represents a key strategy for addressing LIGO content, pedagogical leadership and vision, and well-developed and tested materials that embed an inquiry approach to learning the science. The Exploratorium holds annual trainings and opportunities for LIGO-affiliated teachers to present their own work. A unique outcome of interest to many science educators is how the LIGO SEC programs and participants are melding the informal science teaching and learning strategies and approaches with their formal school settings. At least two SUBR dissertations focused on this unique aspect of the project.

The Baton Rouge Area Foundation (BRAF) gives the project a financial administrative home that is both economical and connected in deep ways to the greater Baton Rouge community.

The contributions of the key partners are shown in Figure 2 on the following page. Each partner's unique assets contribute to its capacities (shown in blue), which together contribute to the infrastructure, vision, and leadership of the Partnership.

Figure 2. Unique Assets and Contributions of LIGO SEC Partners



IV. LESSONS LEARNED

Over the last five years, the LIGO SEC Partnership has created unique teaching and learning opportunities for a wide range of audiences in many institutions, including post-secondary preparation in science and science education at SUBR, professional development and teacher leadership programs, work with classrooms and schools over time, and science education research projects of the post-docs and SUBR graduate students. All of this has helped to weave together a new regional infrastructure for science education.

Along the way, Partnership leaders have learned lessons that are germane to others working to create new arrangements that link science research and science education.

Grow deliberately and build on strengths. LIGO SEC II evolved over time, slowly building on strengths it realized during each phase. Strengths include:

- The effectiveness of the docent program in making a difference for underserved populations considering STEM and STEM-education fields for careers.

- The contributions of the Exploratorium partner, including the physical science exhibits they produce and lend to LIGO SEC and its partners, the teacher training that inspires inquiry-based science practices in the teacher training, and student materials ("snacks").

- University courses that were re-designed to reflect the fundamental and more advanced science related to LIGO, so as to take advantage of the LIGO Science within their community, enhancing science education training with local resources that carry international stature.

Focus on key capacities, leadership and staff. The Partnership has been very strategic in identifying people who have the skills and knowledge necessary to participate fully in the Partnership and to design and deliver quality programs. One representative from the Exploratorium said the following about the staff at LIGO SEC:

> *The folks [at LIGO SEC] are so excellent, and have learned so well. We have worked on a short schedule and they can run with it. I give them a recipe for building a Galilean acceleration inclined plane…and in a few hours they can do a half-day workshop with that. They are so good… We have been coming for long periods over time, and now they can do a lot on their own. And they really are good. I would hire any one of those people to work with me.*

The SUBR faculty and staff, the LIGO SEC staff, Exploratorium and LIGO scientists have found a "groove" in their work together. This is not to say, however, that they do not continue to strive for improvement in their Partnership and their programs.

Be inclusive in planning and ownership of the work, and provide time to plan, design, and review results. While the staff at LIGO SEC would agree that they are extremely busy

with daily operations, they are serious about making sure that they create opportunities to learn new things, plan their work, and review feedback from the leadership, participants, and the evaluators. They understand the value of the various partners and the assets they bring, and are eager to leverage the opportunities they have with them.

REFERENCE

Cho, A. (2015). To catch a wave. *Science,* 347(6226) pp. 1084-1088.

APPENDIX

Evaluation Approach For LIGO SEC Phase II

Roles and tasks

Inverness Research (IR) has served as the external evaluator for LIGO SEC since its inception in 2004. During Phase I, IR served primarily as formative evaluators, monitoring the development of the theory of action and providing feedback about programs and approaches. During Phase II of the LIGO SEC Partnership (beginning in 2009), IR moved into a summative role, carrying out these tasks:

1. Documenting the reach and impact of the programs on important audiences, including teachers, docents and grad students
2. Creating a detailed portrayal of the project as a model, conceptualizing its design challenges and identifying the ways in which the project went about meeting those challenges
3. Reporting formative feedback to the project as our work progressed, using data from surveys, interviews, and site visits. Feedback took the forms of analytic memos, slide presentations, and written reports. *Project reports are available from Inverness Research on request from www.inverness-research.org.*
4. Producing this summary report

Data sources

- Annual site visits (2010, 2011, 2013) to observe programs and interview leaders and docents
- Teacher participant survey (2011)
- Docent Survey (2012, 2013)
- Interviews of stakeholders, graduate students, teacher leaders, and project leaders
- Committee of Visitors site visit. Inverness coordinated the committee and accompanied them on a site visit in 2013. Visitors included directors from three other NSF STC Education and Outreach Centers:
    - Dr. Marco Molinaro from the Center for Biophotonics at the University of California, Davis
    - Dr. Ben Saylor from Sanford Science Education Center associated with the Homestake DUSEL
    - Dr. Lisa Hunter from AKAMAI Workforce Initiative of the Institute for Science and Engineer Educators at the University of California, Santa Cruz.