PROCEEDINGS OF SCIENCE

Forging New, Non-traditional Partnerships Among Physicists, Teachers and Students

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The QuarkNet collaboration has forged new, nontraditional relationships among particle physicists, high school teachers and their students. QuarkNet provides professional development for teachers and creates opportunities for teachers and students to engage in particle physics data investigations and join research teams. Embedded in the U.S. particle research community, QuarkNet leverages the nature of particle physics research—the long duration of the experiments with extensive lead times, construction periods, and data collection and analysis periods. QuarkNet is patterned after the large collaborations with a central management infrastructure and a distributed workload across university- and lab-based research groups. We describe the important benefits of the QuarkNet outreach program that flow to university faculty and present successful strategies that others can adapt for use in their countries.

38th International Conference on High Energy Physics
3-10 August 2016
Chicago, USA

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PoS(ICHEP2016)327

1. The Context

Typical traditional professional development programs are one-time programs with little or no follow up. Programs tend to be short, rarely lasting more than a few days; some may last a week. Programs are usually designed, organized and run by someone FOR teachers rather than WITH teachers.

The nature of particle physics research lends itself to non-traditional professional development programs. Facilities are large as are the collaborations. Collaborations have a central management board with the work distributed among many institutions nationally and internationally. The research requires long development and run times.

There is interest around the world to make science education more closely resemble science research. In the United States the Next Generation Science Standards emphasize 3-D learning—core ideas, crosscutting concepts, and scientific and engineering practices. Student use of data as evidence to make claims and an ability to provide underlying reasoning are key. "The practices better explain and extend what is meant by 'inquiry' in science and the range of cognitive, social, and physical practices that it requires." The framework suggests that students gradually deepen their understanding so that by the time they leave high school all students will meet or exceed the standards.
(http://www.nextgenscience.org/framework-k–12-science-education)

2. The Collaboration

QuarkNet (https://quarknet.i2u2.org) is a national science education program beginning its nineteenth year. QuarkNet partners teachers and students with U.S. physicists participating in experiments at Fermi National Accelerator Laboratory, Batavia, Illinois; the CERN Laboratory, Geneva, Switzerland; at the Sanford Underground Laboratory (SUL); and in non-accelerator/astrophysics experiments. QuarkNet teachers gain valuable research experience and learn to use inquiry-based teaching methods enabling them to teach basic introductory physics concepts in a context that students find exciting.

The QuarkNet leadership team, which includes physicists, educators and teacher-leaders, is well versed in particle physics and has expertise in professional development and teaching and learning. We work with outside evaluators to ensure that our activities make data-driven improvements and an instructional designer to ensure that our classroom materials are of high quality.

QuarkNet is based on a classroom vision where teachers create constructivist learning environments that provide students with opportunities for in-depth engagement in science. Teaching strategies emulate closely the way scientists build knowledge through inquiry. Students develop scientific knowledge and habits of mind by working alongside scientists to make sense of the world using authentic experimental data.

Currently, QuarkNet centers are located at over 50 universities and labs across the United States and Puerto Rico. Over 80 physicists volunteer as mentors to help lead the centers with two lead teachers. Participants include 560+ teachers who have been active in the prior academic year and their students. QuarkNet also includes an international outreach component working with

colleagues around the work to host International Masterclasses and support cosmic ray studies. Over 700 QuarkNet data acquisition cards are available worldwide to collect data; some of it stored centrally with analysis tools in the QuarkNet Cosmic Ray e-Lab.

What makes QuarkNet non-traditional? QuarkNet has been able to secure funding for 20 years of operations. We are currently starting the 19th summer. This allows us to build relationships among participants, the key to our success. QuarkNet provides an open door for teachers into the particle physics research community. Some teachers and students can make meaningful contributions to the experiments in our summer internship programs. From the start, QuarkNet has been a partnership between physicists and teachers, top to bottom. Once we received start-up funding, we hired teachers to help us plan and implement the program. The staff teachers are the key link between the national program and the individual centers. Supporting the staff teachers, a group of fellows, master teachers, provide advice, pilot activities, give workshops and in general support the staff. At each center we provide support for two lead teachers who work with the mentors to provide a program that meets the needs and interests of the local teachers. All of this effort helps bring 21st century physics into classroom across the country.

QuarkNet activities offer teachers and students engagement with scientific investigations. Lead teachers and teachers who lead student research teams hold research internships with mentors. These teachers and students work directly on the mentor's research. Other teachers attend research-based workshops that model scientific research but do not involve teachers directly in the mentor's experiment. In addition, students have their own collaboration, conducting cosmic ray studies with a classroom cosmic ray detector developed by QuarkNet and Fermilab engineers and technicians. Data-based instructional materials prepare students to attend a LHC-based masterclass or conduct their own scientific investigation with the CMS, Cosmic Ray or LIGO e-Lab.

3. Benefits

QuarkNet benefits not only the teachers and their students, but also the physicists. Mentors have opportunities to:

- Share their passion for particle physics.
- "Recruit" the next generation of scientists . . . and new students for the department.
- Get help in their ongoing research from an interested and eager team.
- Use sophisticated cosmic ray experiments to inspire undergraduate and graduate students.
- Learn from the challenges and opportunities of teaching high school physics.
- Reach out to their communities.
- Participate in a credible, impactful outreach program that is highly regarded by our funding agencies.

Teachers have opportunities to work:

- With physicists who are passionate about the work they do
- With real data . . . with all of the joys and frustrations that accompany that
- On "real-world" problems that don't necessarily have clear "back of the book" answers

- On building things! (e.g., detector components or classroom cosmic ray detectors)
- Study topics in 21st century physics.
- Learn science by doing science, not just reading about science.
- Have a sense of wonder about the universe.

- Challenge even the brightest students.
- Motivate students to potentially pursue physics or some STEM field.

Students have opportunities to:

- Learn science by doing science, not just reading about science.
- Go right to the experts; talk directly with physicists.
- Collaborate with students worldwide.
- Experience the environment of a scientific collaboration.
- Conduct their own scientific investigations.

Our outside evaluators have developed a list of factors that contribute to a successful center. First and foremost is strong leadership either from at least one mentor, preferable one who understands education and professional development, and/or from at least one lead teacher. It also helps when the staff teachers and fellows stay in touch with center leaders offering support and following up on any challenges. Maintaining a stable participant base that meets regularly fosters development of a supportive peer group that new participants can join. Participation is enhanced when spread out to include one or more days during the academic year. Local activities need to meaningful particularly with regard to classroom implementation of activities. When some center members find opportunities in their district or professional organization to take on leadership roles, it also has an impact on the center. And finally, when the center becomes a "learning community"with participants fostering and sharing experiences, being a supportive peer group, staying in contact, planning joint activities, etc., the optimal value of being a member of a QuarkNet center is realized.

4. Initiatives in Other Countries

Teilchenwelt (http://www.teilchenwelt.de) began in Germany in 2010. Twenty-nine institutions, universities, institutes and labs collaborate to give deeper insight to the world of particle and astrophysics to teachers and young people. Using authentic scientific data from CERN or from cosmic particles from space, they get a sense of how research at major experiments works. Teachers and students can attend workshops or project weeks at CERN and with scientists at German research institutes.

HISPARC, (http://www.hisparc.nl) gives secondary students an opportunity to participate in real research. Built by students, HISPARC cosmic ray detectors are installed on school and university roofs and connect to a central computer at the university forming a large network or cluster. Currently, there are seven clusters with nearly 100 detection stations throughout the Netherlands. The project has received additional inquiries from abroad where projects can make use of the electronics and software developed by HISPARC.

The Institute for Research in Schools (IRIS) (http://www.researchinschools.org), a new initiative in the United Kingdom, is a school-based program to transform the science experience

in schools. Currently, two hundred twenty six schools are registered with the network where teachers and students can "access top level scientific data, collaborate with scientists around the globe, process information at lightning speed and develop innovative experimental ideas."

5. New Partnership for Outreach

ICHEP offered an opportunity to form a partnership among the Chicago Public Library, conference attendees and Fermilab to bring physics presentations to children in Chicago neighborhoods. Based on Fermilab's successful Classroom Presentation Program (http://ed.fnal.gov/trc_new/demos/) and within the Library's summer program for children and teens, two physicists presented a session at one of 30 branch libraries. Librarians chose one of four of the Fermilab presentations—*Light and Color, Forces and Motion, Charge! Electricity and Magnetism*, and *The Physics of Sport*. We also offered two *Cryogenics Shows*. We offered programs on five of the conference days and provided three orientation sessions, one at the University of Chicago for nine student volunteers; one at Fermilab and another the first day of the conference for attendees. In this way, we were able to offer presentations beginning on the first day. On average 20 children attended a presentation. Total attendance was over 665. Behind the scenes a support team gathered requests from the libraries, developed a schedule for presenters and a schedule for drivers to take kits from library to library, prepared duplicate presentation kits, and led the orientation sessions. Some presenters were veterans having participated in outreach programs back home; others were new to programs for children. As one commented, "I understood how difficult is teach (sic) to children but at the same time I verified the importance of these activities for the society. I want to continue this in my country." And librarians were glad to learn about the Fermilab presentations promising to request other presentations throughout the year.